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IN THEORY AND PRACTICE

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ELECTRICAL ENGINEERING

IN THEORY AND PRACTICE

A CLASS BOOK FOR JUNIOR AND SENIOR STUDENTS
AND WORKING ELECTRICIANS

BY

J. H. ALEXANDER, M.B., A.I.E.E.

LATE LECTURER ON ELECTRICAL ENGINEERING AT THE KILMARNOCK ACADEMY
TECHNICAL CLASSES

AUTHOR OF "MODEL ENGINE CONSTRUCTION"

WITH ONE HUNDRED AND EIGHTY-ONE ILLUSTRATIONS

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PREFACE.

HAVING given Lectures upon Electrical Engineering for several winters to an Evening Continuation Class, composed chiefly of young artisans, in a large engineering and manufacturing town—the class being divided into junior and senior sections, primarily for first and second year men—it occurred to me that if my Lectures were put into printed form suitable for publication their sphere of usefulness would be increased. The present volume accordingly gives the substance of the lectures as delivered, supplemented (where it seemed advisable) by additional matter.

In course of delivery the lectures were illustrated by means of models, apparatus, lantern slides, black-board diagrams, &c., my aim being to put the subject before my students in such a way that they should find no difficulty in acquiring some knowledge of the fundamental principles as well as of the practical applications of electricity and magnetism. It is hoped that the illustrations now given in the printed work will help to answer the same purpose. But readers of the volume should not omit to visit (as students) electric generating stations to see actual work in progress.

A few of the illustrations are from actual machines and apparatus in everyday use, whilst many others are drawn diagrammatically to illustrate the principles upon which the apparatus represented depend for their action. The characteristic curve figures given are reproduced from actual tests taken by myself in an electrical engineering laboratory. With the help of the drawings, if carefully studied, I feel sure that the student will not find much difficulty in following the course of instruction in the text.

I may add that I have omitted all complicated mathematical formulæ which might tend to confuse beginners or those who are not well up in mathematics; but I have given some exercises—worked out at full length—which ought to assist the student by showing him something of the kind of problems to be met with in practice. I am indebted to my assistant, Mr THOMAS BRYDEN, for kindly checking the working out of the exercises.

As the ground covered by this book is somewhat extensive, first-year students may find it advantageous to omit or merely read over Chap. VII. on Alternating Currents, Chap. IX. on Transformers (pp. 100-101), Chap. X. on Alternating Current Motors (pp. 111-114), Chap. XII. on Photometry (pp. 136-137), as well as Chaps. XV., XVI., and XVII., confining their attention in the first instance mainly to the remaining portions of the volume.

I sincerely hope the book will be found to supply a want, and prove helpful as well as interesting to all who may peruse its pages. Any suggestions for the improvement of future editions, with which readers or others may feel disposed to favour me, will be cordially welcomed.

It should be mentioned that the lectures here reproduced have already appeared as a series of articles in the *English Mechanic;* but the articles have since been carefully revised, and where necessary supplemented, so as to bring the work fully up to date as far as practicable.

J. H. ALEXANDER.

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August 1905.

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ELEMENTARY ELECTRICAL ENGINEERING.

CHAPTER I.

FUNDAMENTAL PRINCIPLES.

ELECTRICITY is neither a solid, a liquid, nor a gas. Its nature has not yet been definitely determined, but it is really one "form of energy" which is known to have the same rate of travel as light through space, viz., 192,000 miles per second.

Production of Electricity.—Electricity as it exists in nature is known as "atmospheric electricity." It is produced artificially in many ways, as by friction; by chemical means; by induction, which may be (*a*) electro-static, or (*b*) electro-magnetic; or by the heating of dissimilar metals in contact.

By Friction.—When one body is rubbed over another body, and any difference exists between them in their structure, chemical formation, or capacity for absorbing heat, they both become electrified, and this is shown by their power of repelling or attracting other bodies brought close to them. Thus, a glass rod, warmed and rubbed with silk, attracts little bits of paper, feathers, sawdust, &c., or, when a pith ball is suspended by silk from an insulated glass rod, and the charged glass rod brought near it, the pith ball is attracted and drawn to the rod, and perhaps will adhere to it, showing that it is electrified; for if a rod, before it has been rubbed, is brought near to any of these bodies, no attraction occurs. Sealing-wax rubbed with flannel, as well as rods of resin, ebonite, sulphur, when rubbed with flannel or a cat's skin, do the same thing.

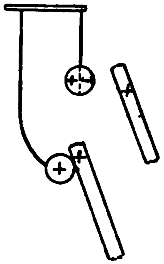

Fig. 1.

The electrified rod induces a charge of electricity of the opposite kind in the pith ball; for instance, if the rod be positively charged, the pith ball will be negatively charged; and unlike charges of electricity attract each other: hence the ball is drawn to the rod. The larger electric charge on the rod cancels that in the ball, and after they have touched the ball gets charged with the same kind of electricity as the rod, then the ball immediately jumps away from the rod, for like charges of electricity repel each other (Fig. 1). So, from this experiment we find that there exist two kinds of electricity: one form called positive electricity, and the other negative electricity; that unlike charges attract each other, and like charges repel each other.

That form of electricity which is produced by rubbing a glass rod with silk we call positive (+) electricity, and that form produced by rubbing sealing-wax with flannel we call negative (−) electricity.

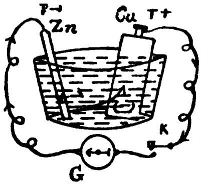

Fig. 2.

By Chemical Means.—Electricity can be produced in this way in much greater quantity than by friction. Take a jar (Fig. 2), suspend in it a plate of copper (Cu), and a rod of zinc (Zn), nearly fill the jar with dilute sulphuric acid and water, and then the battery is complete and the metals used are dissimilar. A terminal should be soldered on to the free end of each, join these two plates by a wire and place a key, K, in circuit. Observe nothing takes place while the circuit is open, as the plates are unconnected; the cell is at rest, no electricity is evolved. If we now press down the key K, a current of electricity will begin to flow inside the jar from the zinc plate or

+ plate (*i.e.*, the plate attacked by the acid), then from the copper plate or (–) plate, round the external circuit back to the zinc plate, and this current continues to pass so long as the key is pressed down and the battery remains active. If a galvanometer, G, is put in the circuit, the deflection of the needle will show that a current is passing. It will be noted here that the zinc plate is the positive plate, and the copper plate the (–) plate, while the terminal of the zinc plate is (–) terminal, and that of the copper plate the positive terminal. In any battery that plate which is more affected than the other one by the acid is always called the + plate, and the terminal by which the current in the external circuit leaves the battery is always called the + terminal, and that by which it returns again the (–) terminal. This combination of a zinc rod and a copper plate, dipping separately into a vessel of dilute acid, is called a *galvanic* cell or *element*. A series of elements connected up together copper to zinc is called a galvanic battery. To cause them to be active they must all have a circuit, completed by a wire, touching the zinc at one end of the series and the copper at the other end; then chemical reaction occurs in the cells, electric energy is set free, and heat is liberated in the metal connections. All bodies cannot complete a galvanic circuit, for if the copper wire connecting the poles of the batteries be replaced by a thread, galvanism does not occur, or electricity is not generated. If one of the wires be severed and a bit of paraffin paper interposed, galvanism does not occur. Thus we see there are substances capable of forming part of a galvanic circuit, and these are called *conductors*. The others, or those which do not permit a current to pass through them, are called *non-conductors* or *insulators*.

(*a*.) *By Electro-static Induction.*—This is the action whereby a body, when charged with electricity, and surrounded by a dielectric or insulating medium such as air, always calls forth on any neighbouring conductor or body placed near it an amount of electricity equal to itself in quantity, but of opposite kind—*i.e.*, if the electricity is + on the one body, it will call forth (–) electricity on the other body, and *vice versâ.* Example: The charged glass rod produces electricity in the pith ball, and the Wimshurst machine produces electricity in, or charges a Leyden jar by this method. Whenever the jar is brought close to the positive conductor of the electric machine (which is hand-driven), a charge is said to pass into the jar, or in other words, we get electricity produced by electro-static induction. The jar becomes now a condenser or electric storage tank, which holds the charge imparted to it for a time until it leaks away, or is discharged by the discharging tongs.

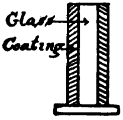

Fig. 3.

The glass of the jar forms the dielectric or insulating medium between the two coats (Fig. 3), which are composed of tinfoil or gold leaf, one outside and one inside, and on the bottom. Extending from the interior through a wooden stopper is a brass rod terminating in a spherical knob; the inside end is attached to a chain lying on the inner tinfoil. To charge the jar the outer coating is held by hand, or otherwise put to earth, while the knob at the same time is placed against or near to the source of electricity, which accumulates in the jar.

To discharge the jar the two coatings must be joined by a conductor, such as a pair of discharging tongs.

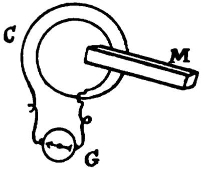

Fig. 4.

(*b.*) *By Electro-magnetic Induction.*—This (Fig. 4) is the method now used to generate electricity on a large scale for lighting and power distributing purposes. The generation of induced currents by the dynamo, or rather the invention of this machine, is entirely due to the discovery of Faraday in 1831. He took a coil, C, containing a number of turns of insulated wire, fixed it upon a stand, and joined the two ends to a sensitive galvanometer, G, the needle of which would move from zero when a current traversed the circuit. Next he took a long steel bar magnet, M, rapidly pushed it through the centre of the coil, so as not to touch it, and found a slight deflection of the galvanometer needle from zero, showing that a momentary current of electricity had been set up in the coil. On again withdrawing the magnet quickly, a second swing of the galvanometer (G) needle took place, but in the opposite direction to the first swing, showing that a current had passed round the coil in the opposite direction; but the moment the relative motion between the coil and the magnet stopped, the galvanometer needle swung back to zero, which showed that the current had also stopped flowing. Faraday next reversed the experiment, and threaded the coil on the magnet, the latter being fixed, with the same results as in the first case. These experiments prove that whenever a magnet is pushed through a wire coil, or whenever a coil is threaded rapidly over a magnet, there is set up, by *induction*, a momentary current of electricity. Now, if we could continue these movements relatively of the coil and magnets to each other for a time, and they were sufficiently rapid, we would set up a constant alternating current of electricity in the coil which might be used to light an incandescent lamp. This experiment can easily be repeated. Suppose we wind a conductor in a number of turns upon a wooden bobbin, B (Fig. 5), and attach the ends to a sensitive galvanometer, G, at some distance off, so as not to be disturbed by the magnetic field of the magnet. If we now slip this bobbin over a steel bar magnet, N S, and leave it there, when at rest we notice no deflection of the galvanometer; but if we slide the bobbin off the magnet, we get a momentary deflection on the galvanometer, showing the presence of a current, and the deflection is greater the quicker the motion. An opposite deflection is got by sliding the bobbin on again. We always get a deflection when taking off the bobbin which is opposite to that caused by sliding it on. The same deflection can be got by holding the bobbin fixed and sliding the magnet, and these two experiments prove

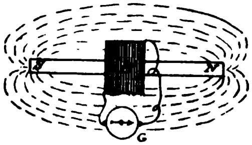

Fig. 5.

that relative motion between a magnet and a conductor always generates an electric current. When the bobbin is in the middle of the magnet, the lines of force, or magnetic field passing through it is a maximum. After it is off they are a minimum, and therefore the electromotive force set up is proportional to the variation of the magnetic field, or lines of force, to the rate of cutting, or velocity of movement, and the length of conductor, or number of turns of wire upon the coil.

We learn from this experiment that a magnet, or magnetism, is able to set up electric currents; further on we will see that the converse process is also true, and that an electric current can set up magnetism. In the first case, to generate currents, we require *motion*, or, in other words, the conductor must be displaced relatively to the magnet. In the second case no motion is required to produce magnetism by a current, but only some source of electrical energy such as a battery.

The above experiment of Faraday led on to the invention of the *magneto-electric machine*, where the movement of the armature of a permanent magnet is used to induce currents in a coil, and later still to the modern dynamo, the essential part of which consists of large bundles of wire loops which form the armature, and this part revolves rapidly, when driven by power, between the poles of a powerful electro-magnet, the armature loops cutting the magnetic lines of force in the field, and so setting up a constant alternating current which, by means of a commutator, is converted into a continuous current, and again, by means of brushes, is led to the external circuit and utilised there for lighting or power purposes. It is important to remember that the reason why a magnet, when thrust through a wire coil, or when a coil is drawn over it, produces electricity is because the coil cuts the lines of magnetic force which pass out from the magnet, and whenever lines of force are being cut by a coil of conductors, an electric current is generated. When the movement stops, no lines are being cut, and therefore no electricity is generated, and the galvanometer needle remains at zero, as we have just seen.

By the Thermopile or Thermo-Electric Generator.—Electricity can be produced by this method, but not as yet in any great quantity. The action depends on the fact that when dissimilar metals, such as antimony and zinc, are joined together and their junctions heated, a feeble current of electricity is evolved. Seebeck discovered this phenomenon. He took a bar of antimony 8 inches long and 1 inch wide (An), soldered a strip of copper (Cu) to the extremities, and bent it into a rectangular shape (Fig. 6). Upon heating one of the extremities of the bar by a lamp, L, a magnetic needle placed within the rectangle was deflected from the magnetic meridian, and tended to set itself at right angles to the bar, showing that a current was passing in the circuit. Dobereiner repeated the experiment, using antimony and bismuth, and found that the heat of the hand applied to one of the extremities was sufficient to deflect a galvanometer needle. Of the metals, bismuth and antimony are the two which produce the greatest effect when used together, bismuth being the most negative, and antimony the most positive of all the metals tried as thermo-electrics, and giving off the highest electromotive force. As the e.m.f. of each couple of elements is very small, we now arrange a number of pairs in series, and these are made into a cubical form, and the free ends are joined to binding-screws, but the amount of electricity given off from this apparatus is small (Fig. 7).

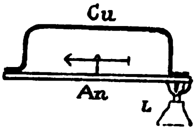

Fig. 6.

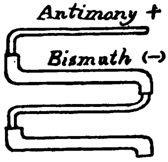

Fig. 7.

Conductors and Insulators.—Bodies, like copper and silver, which become rapidly electrified, and which quickly convey current away from a charged body, are called *conductors;* in these the resistance is practically *nil.* Bodies which allow hardly any current to pass through them, even at high voltages, are called *insulators.* Different bodies possess different conducting powers. All bodies offer some resistance to the passage of electricity.

Good conductors are silver, copper, aluminium, platinum, German silver, iron, &c.

Fair conductors are carbon, acids, the earth, the body of an animal or man, flame, &c.

Insulators are silk, sealing-wax, indiarubber, gutta-percha, shellac, slate, marble, paraffin wax, glass, ebonite, mica, oils, &c.

When we get to electromotive forces of 20,000 and 40,000 volts it is difficult to keep the current from short circuiting, or going to earth, and the very highest insulating material must be used, such as glass, ebonite, oils, &c.

There are no substances known which will insulate lightning discharges, when they meet with obstruction in their paths, as no degree of insulation will withstand the strain set up in these cases, by probably millions of volts, which are necessary to produce the lightning flash.

CHAPTER II.

FUNDAMENTAL PRINCIPLES (*Continued*).

Permanent Magnets.—The term loadstone is applied to an iron ore called the *magnetic oxide* of iron, composed of two atoms of the peroxide and one atom of the protoxide of iron. This substance, being magnetic, will attract iron filings, and having two poles these will alternately attract and repel the poles of another magnet which is free to move.

If a piece of loadstone be drawn along a bar of steel a few times, always in the same direction, the steel bar will become converted into a magnet. But a much more powerful magnet will be produced (Fig. 8) by placing a steel bar inside a coil of insulated wire and passing a strong electric current from a battery, B, or a dynamo around it, at the same time tapping the ends with a hammer during the passage of the current.

A horseshoe-shaped magnet is made in a similar way by first inserting one limb into the coil, turning on the current, tapping the bar, removing the coil, and then doing the same with the opposite limb, at the other end of the coil, and on taking out the bar it will be converted into a magnet, varying in strength with the current employed and with the number of turns of wire in the coil. A bar treated thus becomes a *permanent magnet.* If a magnet be suspended from the middle by a thread or string, or supported on a central pivot, one end will always point towards the Magnetic North, and the other end towards the South. If we cause it to deviate from the position, it will oscillate for a little and at last settle in the same position as at first. That extremity of the bar which points to

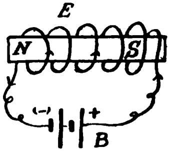

Fig. 8.

the Magnetic North is called the north pole of the magnet. The other extremity is called the south pole. If we present the north pole of one magnet to the north pole of another magnet, both capable of moving freely on their axes, they repel each other. But the north pole of one magnet attracts the south pole of another one, and *vice versâ*. So we arrive at the following rule with regard to magnets, that *like poles repel each other and unlike poles attract each other always*, and we saw (on page 2) that like kinds of electricity repel each other, and unlike kinds attract each other.

Coulomb demonstrated that these attractions and repulsions vary inversely as the square of the distance between the magnets. To preserve magnets they should be kept two in a wooden box, and so placed that their opposite poles N. and S. are next each other, and have keepers between. The horseshoe magnet should have a large wrought-iron keeper placed across its end, as this completes the magnetic circuit in the iron and tends to preserve the magnetism.

A *compound bar magnet* consists of thin ribbons of hard steel, each magnetised separately, and all fixed parallel to each other, with their like poles adjacent, and clamped by brass clamps. In this way a magnet is far stronger than if it was simply a solid piece of steel, for the strength of magnetism does not increase in proportion to the size of the bar.

A steel bar is more difficult to magnetise than a soft iron bar, but it retains its magnetism and does not tend to lose it so readily as the soft iron bar does. On raising the temperature of a magnet to a bright red heat it loses the whole of its magnetism, but recovers it again upon cooling to some extent. Vibration also tends to lessen the magnetism, such as is produced by striking the magnet with a hammer, or letting it fall several times on the floor.

Lines of Magnetic Force.—Take a sheet of white paper, lay it over a straight steel bar magnet, and sprinkle it with iron filings. These arrange themselves in curves which we call the *magnetic lines of force*. Each line forms a closed curve, passing out from a point at one end of the magnet, and re-entering a corresponding point at the other end (Fig. 9). Some of these curves extend beyond the surface of the paper, and seem to get fainter and fainter the farther they go from the poles.

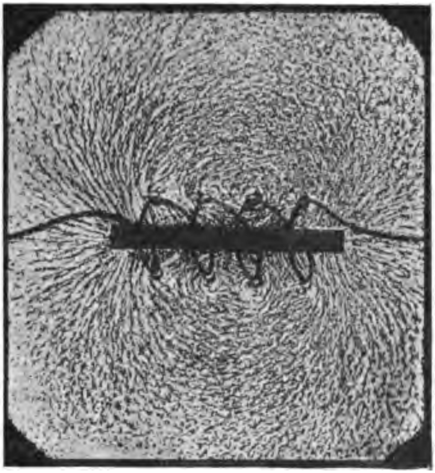

Fig. 9.

These invisible curves do not form in one plane only, but surround the magnet on all sides, the same as if the magnet were surrounded or wrapped up in a piece of cotton wool, this covering representing the lines of force.

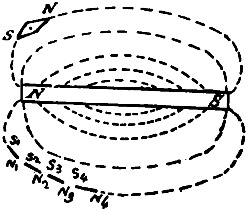

Fig. 10.

If a small compass needle, freely suspended, be placed near the paper it will assume such a position as to form a tangent to the lines of force passing through its centre, and it turns on its axis so that a line joining its poles becomes a tangent to the curve.

From this experiment we regard each particle of the iron filings (sprinkled on the paper) as a very short magnetic needle, and each line of force as a chain of such needles joined together by their opposite poles, S_1 to N_1, S_2 N_2, S_3 N_3, S_4 N_4, and so on (Fig. 10).

Before experimenting, if we had taken a sheet of notepaper which had been dried, after having been drawn through melted paraffin wax, and over this paper had sprinkled iron filings, at the same time having gently tapped the paper, and then had heated it to cause the filings to adhere and become fixed in place, we would have obtained a graphical representation of the lines of force, or external magnetic field, and from this a lantern slide might have been made for purposes of demonstration.

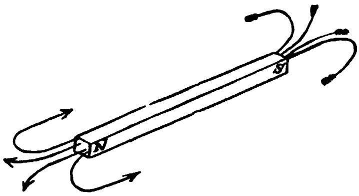

Fig. 11.

These magnetic lines of force start from the N. pole, pass through the surrounding air, enter the magnet by the S. pole, and complete their circuit through the body of the magnet, thus forming a complete circuit, and we can compare the magnet to an arrow-sheath, the lines of force being the arrows (Fig. 11). No magnetic lines of force or curves ever cut, cross, or merge into each other, and they always complete their own circuit. The space outside the magnet, through which the lines of force pass, is called the *external magnetic field*, and the space occupied by the magnet itself is called the *internal magnetic field.*

Theory of Magnetism.—In an unmagnetised bar of steel or iron the molecules are all lying in any kind of direction (Fig. 12, A). They have no definite arrangement, and so are incapable of magnetic action at a distance. If we can rotate these molecules so as to form parallel magnetic chains, and make them all point in one way, to show free magnetism at their ends, then they are able to exert magnetic attraction and repulsion outside the bar, which becomes converted into a magnet (Fig. 12, B). This can be done by rubbing the bar with another magnet, or by passing an electric current around it. The molecules then turn round and arrange themselves in continuous chains, each molecule becoming a little magnet having its N. pole next to, and in line with, the S. pole of the next in the chain, and so on. In soft steel and soft iron the molecules rotate freely, and can be easily turned round into continuous chains; but the harder the steel, the smaller is the angle of rotation, and the stronger must be the magnetising force applied. In soft iron the molecules are easily rotated and easily disarranged, so that the bar easily loses its magnetism, as when struck by a hammer setting up vibration in it. In hard steel, when once its molecules have been rotated they are not easily disarranged, and so the harder the steel the more permanent is its magnetism.

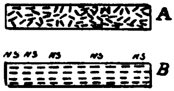

Fig. 12.

This phenomenon can be demonstrated by means of a glass tube filled with iron filings and having a cork in the mouth. If this tube is put inside a helix and a current passed round it, the filings at once begin to arrange themselves in closed chains, parallel to the tube, in fact, the tube becomes a magnet and will attract iron filings and show other phenomena of magnetism. On tapping the tube the magnetism disappears as the closed chains get broken up, and the filings revert to their previous disordered or unmagnetised condition. The partial rotation of the filings does take place inside the tube, and this can be shown by mixing some of the magnetic oxide of iron with water and putting this mixture into a tube with clear glass ends. On looking through the tube endways at a lighted candle it cannot be seen, but, after being magnetised, the light is easily seen as it passes through between the parallel rows of the filings or molecules.

Magnetic Saturation.—When all the molecules in the bar have been completely turned round through the greatest angle they are capable of passing, then the bar is said to be saturated, or completely magnetised, and will not receive any more magnetism, though a stronger current be passed round it.

Magnetic induction must be distinguished from electro-magnetic induction, and by this we mean that if a soft iron bar is laid on a piece of wood, and both of these be laid on a strong bar magnet with the wood between, and tied together with copper wire (Fig. 13), the soft iron bar, by induction, acquires magnetic properties, and soft iron filings will adhere to it as they are attracted. The bar has been acted on by the magnet though separated from it by the piece of wood.

Reversed Polarity.—If a powerful magnet be held in such a way that one of its poles is brought near to the like pole of a weaker magnet, repulsion occurs; but if they be placed quite close or almost touching each other, attraction will result, because the polarity of the weaker magnet is reversed by the stronger one, and this always happens when a weak magnet is suddenly thrust into a strong magnetic field where the lines of force flow in the opposite way to that of the magnets, and the latter is not free to move in order to turn its polarity into the same direction as that of the magnetic field (Fig. 14).

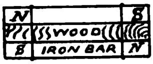

Fig. 13.

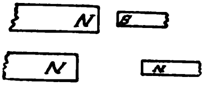

Fig. 14.

Electro-Magnets and Electro-Magnetism.—In 1819 Oersted discovered that if a compass needle was presented to a conductor which was carrying a current, it was deflected, and tended to set itself at right angles to the conductor. If the conductor be placed in the magnetic meridian (an imaginary plane passing through the Magnetic North and South poles and the Zenith), and a compass needle held above it, the N. pole turns to the right of the + electricity current or the direction in which the current flows. If the compass be put under the conductor, the N. pole will point to the left, if the current is flowing in the same direction as before.

When the compass is placed on the west side of the wire and parallel to it, the N. pole will be elevated, but when placed on the east side of the wire, the N. pole is depressed. In Fig. 15, w represents a section of the conducting wire, and the arrows A_1, A_2, A_3, A_4, represent the + direction along the lines of the magnetic field, or whirls, or the direction in which a free N. pole would travel (if there was such a thing as a free N. pole).

In Fig. 20 is also shown a conductor encircled by magnetic lines of force, set up by a current passing through it; compare this with the field surrounding a magnet. (Note these whirls do not revolve around the conductor.)

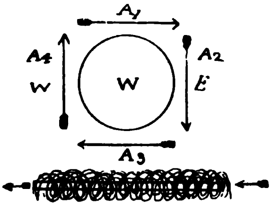

Fig. 15.

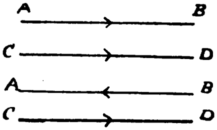

Fig. 16.

Ampere discovered that when two electric currents move in the same direction in conducting wires, placed parallel to each other, they attract, but when moving in the opposite directions they repel. He placed two conducting wires close together, their ends being joined up to a battery (Fig. 16). One wire was arranged so as to be free to move; the other one was rigidly fixed in position. When two currents passed along the wires in opposite directions, the movable wire was repelled, and receded from the fixed wire. When the currents passed in the same direction, the wire was attracted and drawn towards the fixed wire.

Arago and Sir H. Davy observed that a wire conveying a current, if surrounded in a part of its course with soft iron filings, attracted them so long as current passed, but when the current stopped they dropped off (see p. 21). This showed that all the magnetic properties of the wire disappeared when the current ceased to flow.

A little while later Schweigger and Poggendorf showed how this magnetic effect in a wire could be intensified by winding the conductor on a coil of wood with 50 to 200 turns, in the middle of which a pivoted needle was placed, and thereby invented "the electric multiplier," or what is now known as "the galvanometer."

The Electro-magnet was invented by Wm. Sturgeon, of Kirkby Lonsdale. This contrivance is purely a creation of the human mind; so far as we know, no example of an electro-magnet is found in nature. If consists of a bar of soft iron (Fig. 8, p. 9), surrounded by a coil of many turns of insulated wire, E, connected by a battery, B, having one end fixed to S the positive terminal, and the other to the negative terminal. Whenever a current passes round the bar, it becomes converted into a magnet and presents all the properties which an ordinary magnet of hard steel possesses. It has N. and S. polarity, attracts and repels other magnets, and attracts iron filings, needles, &c., as magnetic lines of force are produced or a magnetic field is set up, just as in the case of an ordinary bar magnet; but the moment the current stops the magnetic properties disappear, or nearly so, as a magnetic field is no longer created. Horseshoe electro-magnets are made as well as straight ones (see Fig. 17), in which the U-shaped bar IC is wound with insulated copper coils from end to end on two solenoid brass bobbins, B; or wooden bobbins are filled with the insulated wire and fitted one on each limb of the magnet, both coils being joined together in series, and the free end of each attached to a terminal, T+ and T−. When a current flows through the coils it calls forth a magnetic field, by induction, in the iron core, and this is strong, for it equals the sum of the current field and the induced field in the core. The strength varies with the amount of current passing round the coil, and also with the number of turns surrounding the core, or it is proportional

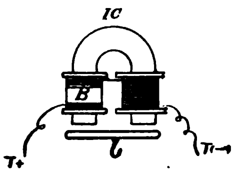

Fig. 17.

to the product of the ampere turns. In an ordinary electric bell we want the magnets to be rapidly magnetised and demagnetised whenever a current of short duration passes through them, and in order to effect this the cores are made very short. When a steady continuous pull by the magnets is required, then long solenoids and cores are used, as this increases the resistance of the magnetic circuit, or reluctance.

The strength of a magnet pole is got by measuring the attractive force or repulsion exercised on another pole, the force equalling the product of the two polar strengths. Let M equal the strength of one pole and M^1 that of another one. Then the force of their repulsion or attraction is $M \times M^1$; but this varies inversely as the square of the distance in centimetres, so the force F between the two magnets is expressed by the formula—

$$F = \frac{M \times M^1}{d_2}.$$

A *unit magnetic pole* is a pole that, when placed at a distance of 1 centimetre from a similar pole of equal strength, repels it with a force of 1 dyne. Magnetic moment, ML, is the product of the pole strength, M, in dynes, into the length, L, in centimetres between the poles.

As in an electric circuit, we find that the current sent along it is directly proportional to the e.m.f. or electromotive force, and inversely as the resistance, for by Ohm's law $C = \frac{E}{R}$. In a similar manner we find that the number of lines of force produced in an electro-magnet is directly proportional to the magneto-motive force and inversely as the magnetic resistance, for the total number of lines of force—

$$\text{Magnetic field} = \frac{\text{magneto motive force}}{\text{magnetic resistance}}.$$

Magneto-motive force means the total magnetising force, and this is proportional to the current strength expressed in amperes and the number of convolutions in the solenoid, or, in other words, to the "ampere turns."

Magnetic resistance or reluctance is directly proportional to the length of the circuit l, and inversely proportional to the sectional area a. Thus magnetic resistance

$$=\frac{l}{a \times \mu}.$$

Here μ = the permeability, or the relative capacity for conducting lines of force; a is the sectional area measured in square centimetres. Suppose the number of convolutions on each limb of the magnet is 300, then $N = 2 \times 300 = 600$. Current strength = 1 ampere, length of magnetic circuit = 16 centimetres, and area of core, and armature $a = 4$ sq. centimetres. Permeability of the iron is, say, $\mu = 500$.

$$F = \frac{\frac{4\pi}{10} \times C \times N \times a \times \mu}{2}$$

$$F = \frac{1{\cdot}2566 \times 1 \times 600 \times 4 \times 500}{16} = 94{,}245$$

F = the total field strength, and 1·2566 are the ampere turns.

This means, if we could cut the magnetic circuit across, we would find 94,245 lines of force passing across between each square centimetre of the opposite faces of the iron. If a solenoid coil contains no iron core, a certain number of magnetic lines, or a certain density of field, will pass through it. If we insert an iron core, this multiplies the number of lines of force previously existing in the field, as iron is strongly paramagnetic, and the number of lines is sometimes increased 10,000 times to what they were when the coil contained no core, for iron gives an easier path for these lines to travel through than air.

When a magnetic field is set up in air the flow of lines per unit area is denoted by the symbol H. When the flow of force occurs through iron it is called induction, and the total number of lines passing through it per square centimetre of cross section is called B, and this shows the ratio in which the presence of iron increases the number of lines of force previously existing in a magnetic field through air. Let H represent unity, or the permeability of air, which is taken at 5,000 lines per sq.

cm., then the permeability, or specific magnetic conductance (called μ), of paramagnetic bodies as iron is greater than this, *i.e.*, B is greater than H. On the other hand, in diamagnetic bodies where their permeability or μ is less than unity, B is less than H (for instance, zinc).

$$\text{The ratio of } \frac{B}{H} = \mu, \text{ also } B = \mu H.$$

Susceptibility we define as the ratio of magnetic intensity to magnetising force; this is called κ. $\kappa = \frac{I}{H}$, where I = magnetic intensity, and H = magnetising force.

Free magnetism is set up whenever the lines of a magnetic field complete their circuits through air, as between the poles of a magnet, but in the case of a uniformly magnetised iron ring there is none, as all the lines of force complete their circuits through the iron.

Hysteresis is that property of iron by which the induction or magnetic condition of the bar lags behind the magnetising force applied. In order to magnetise a piece of iron, electrical energy must be expended, or work done to overcome intermolecular friction (see p. 12), in order to turn the molecules and arrange them in straight lines, and the energy required to do this, is greater the harder the brand of iron used for the experiment. In overcoming the friction heat is set up, and owing to this, loss of energy results. From these causes only a part of the energy is again given out as an electric current, on demagnetising the bar, so the loss is considerable, and it is given by Prof. Ewing as 16,300 ergs per c.c. per cycle for soft iron, and 200,000 ergs per c.c. per cycle for Tungsten steel.

The iron used in dynamo-electric machines must have a certain magnetic quality. This can be found for any sample by subjecting the iron to certain tests and plotting a curve from the results, which is called the curve of magnetisation. For further information on this subject see Kapp's "Dynamos and Alternators."

CHAPTER III.

ELECTRICAL CURRENT.

The Flow of Current.—When an insulated body has received a static charge of electricity, and is brought near to another insulated body, which has been electrified to a greater or less degree, immediately an electric stress is set up in the space, or air, surrounding the two bodies which varies in intensity with the degree of electrification of the bodies, and, if they be joined together by a conductor, a rush of electricity quickly takes place from the more highly charged body to the other one which we call a "discharge," and the stress is relieved as both bodies have lost their charges and become neutral. In the case of a copper and zinc plate in a battery where they are connected up in circuit with each other, the discharges, which should restore equilibrium and render the plates neutral, set up chemical changes in the liquid in the cell, for zinc is dissolved and converted into zinc sulphate ($ZnSO_4$). These chemical reactions, in turn, set up fresh electrical differences between the plates, which are followed by other discharges, and so on. These charges follow very rapidly, and appear to our eyes as a continuous current of electricity flowing in the battery circuit.

We liken the flow of electricity along a conductor to water flowing through a pipe. We say the water flows through a pipe at the rate of 1 gallon per second; similarly the unit of quantity, as will be shown, is one coulomb per second.

When a current passes along a conductor the flow of electricity is caused by the difference of potential or pressure between its ends, and the current flows from the higher potential to the lower potential always. The quantity which passes depends on the difference of pressure or potential set up. Suppose we have a wire, the potential of which is 5 volts at one end and 2 at the other, then the difference of 3 volts causes the flow of electricity along it. The flow is the same at all parts of the circuit. In Fig. 18, B = battery, C = conductor, and PL = potential line. When a current passes along a conductor it can neither be seen nor heard, and its presence is only detected from its effects on the conductor. It produces three things —it sets up *magnetism* around the conductor, it produces also *heating* and *chemical effects*.

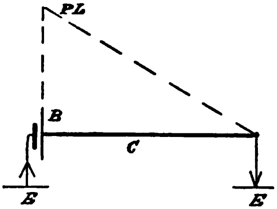

Fig. 18.

(*a*.) *Magnetic Properties.* — When a current passes along a conductor it sets up a magnetic field or magnetic whirls around the conductor, which radiate from it on all sides, forming as it were a circle round it, just as if the conducting wire was put inside an ordinary corkscrew, the screw representing the whirls. These whirls form planes of concentric circles round the conductor, which become of greater and greater diameter as the current increases, and so pass farther and farther out from the wire. The conductor always forms the centre of the whirls, and when we stop the current the whirls disappear and pass again, as it were, into the wire. Their intensity is always proportional to the current strength, and inversely to the distance, for a pocket compass, if held close to the conductor, is acted on more intensely than when held a little way off.

Fig. 19.

The magnetic field surrounds the conductor (Fig. 15), but does not revolve around it; however, we assume there is a positive and a negative direction along the lines of force, the first being the direction in which a free N. pole would travel (see p. 15).

The magnetic lines of force always follow a circular direction round the wire, and a compass needle held near the wire always sets itself as a tangent to these circles. Suppose we take an ordinary corkscrew (Fig. 19), and assume that the longitudinal direction of the screw, either into or out of the cork, represents the direction of the current, then the positive direction of the lines of force, or direction which the flow will be, is that in which the handle rotates, so that when a current in a conductor is reversed, the positive direction of the lines of force will be in the opposite way to what it was previously. In Fig. 20 the arrow represents the current as passing down C (the conductor), and the circle with arrows represents the direction in which a free N. pole would travel, or, in other words, the positive direction of the lines of force round the wire.

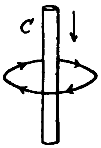

Fig. 20.

(*b.*) *Heating Effects.*—Whenever a current passes along a conductor it raises the temperature of the conductor in overcoming its resistance, and thereby heats it. The smaller the conductor the greater the resistance it offers to the passage of the current, and so the greater is the heat generated.

The heat generated in calories in a given time, by a certain current passing through a conductor of fixed resistance, is proportional to the square of the current, the resistance of the conductor and the time of flow, divided by Joules equivalent, or—

$$\text{heat} = \frac{C^2RT}{J}.$$

J equals 14,600,000 ergs, and is expressed as $4{\cdot}16 \times 10^7$ ergs, and it is defined as the heat required to raise ·24 gram water by 1° C., to find the heat generated.

Exercise.—We take No. 20 conductor, which has a resistance of 0·023ω per yard, and send a current of 1 ampere through it for one minute or 60 seconds. Then the heat developed is—

$$\text{Calories} = C^2 \times T \times R \times {\cdot}24$$
$$1^2 \times 60 \times {\cdot}023 \times {\cdot}24 = 0{\cdot}33 \text{ calorie.}$$

(*c.*) *Chemical Effects.*—When a current is passed through certain compound liquids such as sulphate of copper, cyanide of silver, &c. (which can convey it), decomposition takes place, and the amount of metal deposited, from an acid solution of its compounds, always bears a fixed relation to the current strength and the time, so that it is possible to calculate the current strength from the amount of metal deposited.

The apparatus to calculate the current strength from the amount of metal deposited is shown in Fig. 21. Electrolysis or chemical deposition takes place in V, the voltameter, which contains a solution of a copper or silver salt, which may be acidulated to render it a better conductor. In the liquid are suspended two plates of copper, each attached to a terminal. The one by which current enters is called the anode, A, or loss plate; that by which current passes out is called the cathode, or gain plate, C. As the deposit always occurs on the cathode, or negative plate, the other plate loses in weight slightly as it gets eaten away. After joining up the apparatus, as in Fig. 25, we first get a suitable deflection by means of a trial plate, which shows that it is in working order. Then we remove this plate, and in its stead put in the cathode or gain plate, which has previously been washed, rubbed over with emery-paper, carefully dried by heating, weighed (with a chemical balance), and its exact weight noted. With watch in hand, we close the key K in circuit, note the exact minute when the current was turned on, and allow it to flow for thirty minutes, or even an hour (perhaps the longer time will give the best results), during which time we carefully adjust the regulating rheostat R, if necessary, to keep the galvanometer needle G at the same deflection during the whole experiment, and so keep the same current strength flowing. When the time has expired, we open K, remove the gain plate, carefully wash it in water, dry it by heating, and again weigh it in the same balance, and note the increase in weight. This increase gives the amount of copper deposited on the plate in grams or grains. (The anode plate loses always in weight by a definite

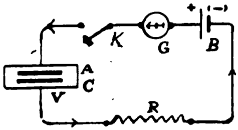

Fig. 21.

amount, but this plate is never used to estimate current strength.) The weight of metal deposited from a solution of any of its salts by a current of C amperes in T seconds is got by the formulæ—

$$W = CTZ, \text{ and } C = \frac{W}{TZ}.$$

Where C = current, W = deposit in gram, T = time in seconds, Z = the electro-chemical equivalent to the metal.

Suppose the weight of cathode plate at the beginning = 20·392 gram.
Weight of cathode plate at the end of test = 20·424
Gain in Weight = ·032

Mean galvanometer deflection 8 divs., time = 60 minutes. Then—

$$C = \frac{W}{TZ} = \frac{\cdot 032}{60 \times 60 \times \cdot 00032709} = 0\cdot 0271 \text{ ampere,}$$

or, if the weight deposited is unknown, but all the other factors are known, then—

$$W = CTZ = 0\cdot 0271 \times 60 \times 60 \times 0\cdot 00032709 = \cdot 032 \text{ gram.}$$

The electro-chemical equivalents of the elements can be got from an electrical engineering pocket-book, such as that of Munro and Jamieson, and the above ·00032709 is the electro-chemical deposit in grammes per coulomb for copper (cupric).

Voltage.—As water always flows from a higher to a lower level, so in like manner electricity always flows along a conductor from a higher to a lower potential. In Fig. 22 T is a water-tank from which a horizontal pipe, HP, passes, having its mouth turned downwards. By placing two or three vertical pipes, P_1, P_2, P_3, in HP the water is found to stand at a less height and pressure in each. The farther it is removed from T and the height at which it stands in each is proportional to the hypothenuse of the triangle drawn from the surface of the water in T to the outlet of HP and coincides with it. In like manner, if a battery be joined in circuit with a conductor of uniform resistance throughout its entire length, a uniform fall of potential from maximum to zero will occur when a current flows, and this can be indicated by a sloping line (Fig. 23). But if parts of the circuit have greater resistance than other parts, from being composed of different materials, or being of greater cross-sectional area, then the fall of potential will be greatest along the part offering the greatest resistance. Let C be the copper conductor, R a German-silver resistance, and G the galvanometer. The current flows in a positive to a negative direction, and, as shown by the vertical and sloping lines, the fall of potential is proportional to the resistance. Only a slight fall occurs in C, as copper is a good conductor, and offers the least resistance in the circuit. A greater fall occurs in R, while the greatest fall occurs in G, as this has the greatest resistance. These are shown by the different slopes of the dotted line AFD.

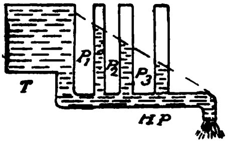

Fig. 22.

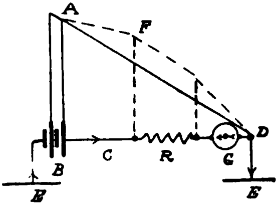

Fig. 23.

We always assume the earth as being at zero potential, and the potential of any body is the difference between its potential and that of earth, so "potential" is only a relative term, and we compare the potential of one body with that of another. If two insulated bodies be joined together by a conductor, an electric charge may or may not pass from the one body to the other. It will pass only if one body be electrified to a higher potential, or contains a greater electric charge than the other does; then an electric current will pass between them. When a positively charged body is joined by a conductor to earth, an electric charge passes to earth, for the body is at a higher potential or electric pressure than the earth is. When a negatively charged body is joined to earth, a charge passes from earth to that body, because the earth is at a higher potential than that body. In Fig. 24 there are two insulated bodies—one is electrified positively (shown by the sign +) and the other negatively (shown by the sign −). Let zz be the zero line, then the potential or electromotive force of the first is represented graphically by the dotted lines AB, and that of the second by CD above and below zz respectively. If both bodies be now joined by a conductor, a discharge will take place from one to the other, causing the charges to cancel each other, and the potential line of each body will coincide with zz, the zero line, as both have become neutral.

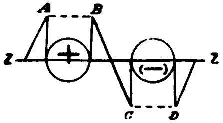

Fig. 24.

If a sphere charged with positive electricity be kept far enough apart from any disturbing body, then the magnetic lines of force set up on it are radial, equidistant in position, and their direction is outwards (Fig. 25). In a negatively charged sphere the lines of force project inwardly (Fig. 26). If a positively charged body be brought near to a negatively charged body, many of these lines bend, turn round, and concentrate themselves in the space between the two bodies, and consequently attraction results (Fig. 27). This imparts motion to the bodies, if one or both be free to move, and this motion implies capability for doing work; but this last and "potential" are convertible terms, and we call its potential the degree of electrification of any body.

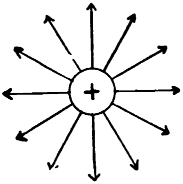

Fig. 25.

Resistance.—When water flows through a pipe, the flow will be fastest where the pipe is smooth inside, free from inequalities, and remains of the same calibre throughout its length. In short, it must offer no obstruction or resistance to the flow. In the same way the flow of current along a conductor will take place more easily and in greater quantity according as the conductor has the power of making the current pass easily through it, or, in other words, offers the least amount of resistance or obstruction to the current's path. All metals are conductors of electricity, but they do not all do so equally; for instance, silver and copper are better conductors than iron or platinoid wire. The *resistance* of a conductor is always in proportion *to its length.* Thus, a conductor 6 feet long will offer twice the resistance to the passage of the current from what another conductor 3 feet long will do, provided both are of the same gauge. As a conductor heats by the passage of current its resistance increases. The *material* affects the conducting power. Copper and silver are the best of all, for they offer the least resistance. The sectional area of a conductor affects the resistance, for, if we double the area of a pipe through which water flows, we allow twice as much water to pass. So with electricity: doubling the cross-section of the conductor allows twice as much current to pass; therefore, resistance varies inversely with the area of the cross-section. As wires are round, to find their area we say that the area of a circle varies as the square of its diameter; for instance, if we have two conductors one $\frac{1}{8}$ inch thick and the other $\frac{3}{8}$ inch thick, their areas are not proportional as 1 to 3, but as the square of those figs., viz., 1 to 9, so that the wire which is three

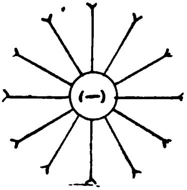

Fig. 26.

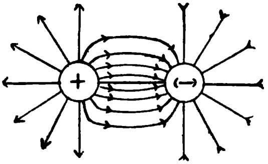

Fig. 27.

times the diameter of the other offers only $\frac{1}{9}$th of the resistance offered by the thinner wire.

The resistance of wires uniform in all respects except thickness varies inversely as their weights. Thus, if one mile of copper wire weighs 100 lbs., and has a resistance of 10 ohms, and an equal length of similar copper wire weighs 160 lbs., the resistance of this last will equal $6\frac{1}{4}$ ohms, for—

$$160 : 100 :: 10 : x = 6{\cdot}25\,\omega.$$

The resistance of a conductor of a given length and thickness depends upon the relative *resistance* of the material of which it is composed.

Specific resistance means the resistance in millionths of an ohm of a centimetre cube, between two opposite faces of a metal, and in many text-books tables are given, showing the specific resistances of chemically pure metals such as silver, copper, iron, German silver, &c., which the student should consult.

Electrical Units.—The *Ampere* is the unit of the rate of flow of current, and is so called after Ampere, the propounder of the Amperian theory of electric currents. The symbol is A or C. It is a $\frac{1}{10}$th part of a C.G.S. unit and is expressed as 10^{-1}. It is that current which deposits 0·00118 gram of silver per second from an aqueous solution of silver nitrate of a standard strength. By the standard of current we mean that current which, in passing through the Board of Trade's Standard instrument (both in a forward and backward direction in the coils), produces a change of forces which, in turn, act on the suspended coil in its sighted position, and this action is just balanced by gravity acting on an iridio-platinum weight.

The *Volt*, named after the scientist Volta, is the name given to the unit difference of electrical pressure. The symbol is E. It equals 10^8 C.G.S. units, and is 0·926th part of the e.m.f. of a Daniell cell, or 0·697th of the e.m.f. of a Clark cell, at 15° C.; also that e.m.f. which maintains a current of 1 ampere in a conductor whose resistance equals 1 ohm.

The standard of e.m.f. is defined in England as the $\frac{1}{100}$ part of the pressure which causes a certain deflection of a Kelvin electro-static voltameter (of the multicellular type), which is kept at the Board of Trade Electrical Standardising Laboratory in London.

The *Ohm* is the unit of resistance, so called from Dr Simon Ohm, who discovered the relation between currents, voltage, and resistance known as Ohm's law. It equals 10^9 C.G.S. units, and is represented by the resistance offered by a column of mercury 106·3 cm. long, 14·1521 grain mass, of constant cross-sectional area, at the temperature of melting ice to an unvarying strength of current. The standard of resistance is that between the terminals of a standard platinum silver coil (in the Board of Trade's Laboratory) to the passage of a constant current at a uniform temperature of 15·4 C.

The *Watt*, so called in memory of James Watt, the great engineer, is the unit of electrical power, and to find in volts the power of the current in amperes developed we multiply the total pressure by the current, or multiply the current in amperes squared by the resistance, or again divide the square of the voltage by the resistance.

Thus—

$$\text{C} \times \text{E} = \text{watts}, \ \text{C}^2 \times \text{R} = \text{watts}, \ \frac{\text{E}2}{\text{R}} = \text{watts}.$$

We define the watt as the power conveyed by one ampere through a conductor whose ends differ in potential by one volt, or the rate of doing work when one ampere passes through an ohm. It equals 10^7 ergs per second, and therefore equals $\frac{1}{746}$ part of an electrical horse-power. Symbol = W.

The *Kilowatt* stands for 1,000 watts, and is the commercial unit of power. The symbol is "KW." As the value of the watt is very small and inconvenient to use to denote the power of large dynamos, the kilowatt is preferable to denote the power of the machine. Suppose a dynamo gives off 500 amperes at 120 volts, the energy given out is at the rate of—

$$\text{C} \times \text{E} = \text{W} = 500 \times 120 = 60{,}000\,\text{W}.$$

Expressed in E.H.P., this would be—

$$\frac{\text{W}}{\text{E.H.P.}} = \frac{60{,}000}{746} = 80{\cdot}4 \text{ E.H.P.}$$

It is more convenient to denote the power as—

$$\frac{60{,}000}{1{,}000} = 60 \text{ kilowatts or a 60 unit machine.}$$

Kilowatts can be easily converted into horse-power, for 1,000 is slightly more than $1\frac{1}{3}$ times 746, therefore 1 kw. = approximately $1\frac{1}{3}$ E.H.P.; and the E.H.P. of a dynamo is got by adding one-third of the number of its commercial units of power (kilowatts) to that number of units (kilowatts). Thus in the above case the E.H.P. of the 60 kw. machine is—

$$60 + \tfrac{1}{3}\text{rd of } 60 = 60 + 20 = 80 \text{ E.H.P.}$$

The *Horse-Power* is the practical unit of power, and power is the rate of doing work. The absolute unit of power is one erg per second, whilst 10,000,000 ergs per second is the practical unit of power in the C.G.S. system, as already explained. One H.P. is 746 watts, or 7,459,571,687 ergs per second. The French horse-power is 735·75 watts = 0·9863 E.H.P. (English).

The *Joule*, the unit of heat or work, equals 10^7 C.G.S. units of work or ergs. It is the work done or heat formed by a watt in one second, or by an ampere flowing through 1 ohm's resistance, or by a coulomb running down through a D.P. (difference of potential) of 1 volt. It is the heat which raises 0·24 gram water 1° C., and it equals 0·7373 foot lb.

$$\therefore \text{E C T} = \text{C}^2 \text{R T} = \text{E}^2\text{T} \div \text{R} = \text{Joules.}$$

The *Watt-hour* is a more convenient unit, and is the work done in 1 hour by 1 ampere flowing along a conductor under 1 volt pressure.

The *Kilowatt-hour*, or Board of Trade unit, of electrical energy is the legal quantity fixed by the B.T. for public supply purposes, and is the quantity of energy supplied in one hour by a current at such a pressure that the product of volts, amperes, and hours come to 1,000. These are called Watt-hours.

Exercise.—A current of 10 amperes at 100 E. is supplied for one hour = 1 B.T.U., for 10 × 100 × 1 = 1,000 W. = 1 kw., and 1kw. supplied for one hour = 1 B.T.U. A current of 4 amperes, at 20 E., is supplied for $12\frac{1}{2}$ hours; this = 1 B.T.U., for 4 × 20 × 12·5 = 1,000 W. = 1 kw., and 1 kw. supplied for one hour = 1 B.T.U.

Suppose we have a dynamo supplying 400 A. at 105 E. The energy is given off at the rate of 42,000 watts. Therefore, in 1 hour, 400 × 105 × 1 = 42,000 watt-hours would be supplied. Or,

$$\frac{42{,}000}{1{,}000} = 42 \text{ B.T.U. (Board of Trade Units).}$$

But—

$$1 \text{ B.T.U.} = \frac{1{,}000}{746} = 1\tfrac{1}{3} \text{ H.P. hour,}$$

or, $42 \times 1\frac{1}{3} = 56$ horse-power hours.

How many B.T.U.'s would light 50-volt 16 c.p. lamps for 5 hours, if each lamp takes 1 ampere? Each lamp takes C × E = 1 × 50 = 50 W. Therefore, 5 lamps take 50 × 5 = 250 W. Or—

$$\frac{\text{W}}{1{,}000} = \frac{250}{1{,}000} = 0\cdot25 \text{ B.T.U.'s per hour.}$$

Therefore, in 5 hours, 5 × 0·25 = 1·25 B.T.U.'s would be required.

The *Coulomb* (symbol Q) is the unit of the quantity of electricity in any circuit, and it is so called from Coulomb, who discovered the law of electric and magnetic attraction, and who invented the torsion balance. It is equal to 10^{-1} C.G.S. units of quantity, and is that quantity of electricity represented by 1 ampere flowing for 1 second along a circuit.

Capacity.—This unit is called the Farad, a name derived from Michael Faraday; the symbol is K. It equals 10^{-9} C.G.S. units, and is defined as that capacity which will contain one coulomb at the potential of one volt.

The *Microfarad* is one-millionth part of a farad. Symbol M.F.D.

The *Milliampere* is $\frac{1}{1000}$ part of an ampere.

The *Megohm*, Symbol Ω (Greek omega) = 1,000,000 (million) ohms.

The *Michrom* = $\frac{1}{100000}$ of an ohm

The *Henry* is the unit of induction in a cuit, and is set up when the inducing current varies at the rate of one ampere per second, and the e.m.f. = 1 volt. This equals 10^9 C.G.S. units. L denotes inductance.

In Fig. 28 we give a few electrical symbols (taken from Munro and Jamieson's "Electrical Pocket-book") to show how electrical apparatus and machines are represented diagrammatically:—

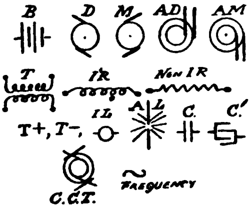

Fig. 28.

"B is a battery, the long stroke being +, and the short stroke (−). D is a continuous-current dynamo. M a continuous-current motor. AD and AM are an alternating-current dynamo and motor. T is a transformer. IR is an inductive resistance. N. IR is a non-inductive resistance. T+, T− are terminals. AL is an arc lamp. IL is an incandescent lamp. C C are condensers. CCT is a constant-current transformer. ∽ stands for frequency."

Fundamental Units:—The *Centimetre* (0·3937 inch) is taken as the unit of length.

The *Gramme* (15·432 grains) is taken as the unit of mass.

The *Second* is taken as the unit of time, and the system, founded upon length, mass, and time, is called the C.G.S. (centimetre-gramme-second), or absolute system of units.

Heat Units.—1 *British Thermal Unit* is the heat which raises 1 lb. of water from 60° F. to 61° F.

1 *Calorie or Therm* is the heat which raises 1 gram. water, at 4° C., through 1° C. (French unit).

CHAPTER IV.

ELECTRICAL CURRENT (*Continued*).

Ohm's Law.—Dr Simon Ohm, a German physicist, in 1827 announced in his "Mathematical Theory of the Galvanic Current," that a certain relationship exists between current, voltage, and resistance, and it is called Ohm's law after him. He discovered that the ratio of e.m.f. to the current, in the same conductor, is a constant or $\frac{E}{C}$ = a constant quantity, where E = the electromotive force, and C = current strength. This constant quantity was found to be equal in all cases to the total resistance of the circuit, and is confirmed by experiment. Now $\frac{E}{C} = R$; this expresses in algebraic form the relationship known as Ohm's law. If any two of these quantities, such as current, voltage, or resistance, are given, we can easily find the third, for, by transposing one term, we get—

$$E = C \times R,$$

and we also get—

$$C = \frac{E}{R},$$

and we say that—

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}, \text{ or } C = \frac{E}{R},$$

where ohmage denotes the number of ohms resistance in the circuit. Expressed in words, this law means that the strength of the current varies directly as the e.m.f., and inversely as the total resistance of the circuit.

Exercises.—(1.) A battery sends a current of 3 amperes through a circuit, the voltage is 9 volts. What is the resistance in circuit?

$$\text{Since } R = \frac{E}{C}, \text{ then } R = \frac{9}{3} = 3\omega.$$

(2.) What pressure or e.m.f. is required to send 20 amperes through a resistance of 4ω?

$$\text{Since } E = C \times R, \text{ then } E = 20 \times 4 = 80 \text{ volts.}$$

(3.) In a 100-volt circuit the total resistance is 20ω. What current will flow?

$$\text{Since } C = \frac{E}{R}, \text{ then } C = \frac{100}{20} = 5 \text{ amperes.}$$

A current of 10 amperes passes through a circuit of 5ω resistance. What power in watts is absorbed? By Ohm's law—

$$E = C \times R = 10 \times 5 = 50 \text{ volts.}$$

But we already saw that—

$$W = C \times E = 10 \times 50 = 500 \text{ watts.}$$

What horse-power is absorbed in lighting five hundred 110-volt lamps arranged in series when the resistance $= 220\omega$? By Ohm's law, each lamp requires—

$$C = \frac{E}{R} = \frac{110}{220} = 0{\cdot}5 \text{ ampere.}$$

Therefore, 500 lamps require—

$$500 \times 0{\cdot}5 = 250 \text{ amperes,}$$

and the power absorbed—

$$W = C \times E = 250 \times 110 = 27{,}500 \text{ watts.}$$

Then—

$$\frac{27{,}500}{746} = \text{nearly } 37 \text{ E.H.P. (electrical horse-power).}$$

The Arrangement of Circuits.—The MHO is the unit of electrical conductance; it is just OHM, the unit of resistance, spelt backwards. The conductance of any circuit is the reciprocal of its resistance. If the resistance $= 2\omega$, the conductance will $= \frac{1}{2}$ mho; again, if the resistance $= 8{\cdot}5\omega$, then conductance = the reciprocal of $8{\cdot}5$ = (reduce to a vulgar fraction) $\frac{85}{10}$—*i.e.*, $\frac{10}{85} = 0{\cdot}12$ mho. To get the reciprocal of a number express it as a vulgar fraction and invert. Thus the reciprocal of any number n is got by dividing it into unity —*i.e.*, the reciprocal of $n = \frac{1}{n}$. Hence the reciprocal of $0{\cdot}05 = \frac{1}{0{\cdot}05} = 20$, for the product of any number multiplied into its reciprocal = unity: thus $0{\cdot}05 \times 20 = 1$. The resistance, on the other hand, is the reciprocal of its conductance. If the conductance $= \frac{2}{3}$ m h o, then resistance $= \frac{3}{2}$ ohm, or $1{\cdot}5\omega$.

Open circuit (Fig. 29) is that arrangement in which the current is not able to pass into the conducting part of the circuit, and this takes place in every circuit when the switch, or key, K, is on the off position, as the circuit is broken. By electric circuit we mean the path traversed by an electric current, and it is composed of the source, which may consist of one cell, or several cells, forming a battery, B (Fig. 30), and the conducting part joining the terminals of the source, and this may consist of wires, measuring instruments, lamps, &c. Now the terms "series" and "parallel" denote the methods of joining up the separate parts of the circuit.

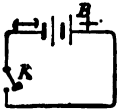

Fig. 29.

"*In series*" we define that arrangement in which the positive terminal of one cell, B, is joined to the negative terminal of the next one, so that the whole form a series of parts, through which the same current passes (Fig. 31). By this arrangement the total resistance in circuit increases.

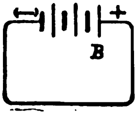

Fig. 30.

In Fig. 31 let the resistance of B $= 320\omega$
" " " G $= 20\omega$
" " " $R_1 = 2\omega$
" " " $R_2 = 2\omega$
344ω

Therefore, as all the resistances are in series, the total R in circuit $= 344\omega$; thus, when the circuits are arranged in series it is very easy to find the total resistance, for it is simply the sum of the several resistances.

Exercise.—Three lamps of 55, 50, and 45w. resistance respectively are arranged in series. What E.H.P. is absorbed if five amperes is sent through them (neglecting the resistance of the conductors)?

$$\text{Total R} = 55 + 50 + 45 = 150\omega,$$

and by Ohm's law the voltage required to send five amperes through them is—

$$\text{E} = \text{C} \times \text{R} = 5 \times 150 = 750 \text{ volts.}$$

Therefore E.H.P. absorbed

$$= \frac{\text{C} \times \text{E}}{\text{E.H.P.}} = \frac{5 \times 750}{746} = 5$$ (electrical horse-power).

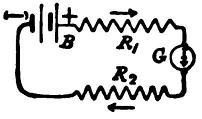

Fig. 31.

"*In parallel*" is that arrangement in which the similar terminals, or plates, of the cells are connected to one conductor, and the other terminals or plates to the other conductor, so that the circuit is made up of several separate paths for the current to flow. In this method the conductivity of the conductors is increased, and consequently the resistance of the circuit is decreased (Fig. 32). In Fig. 33 the current from the battery B will divide at C, some passing round A branch, and the remainder by B branch, both currents joining again at D, and passing back to the battery. The current always divides between the two paths, according to the joint conductivity which is the sum of the two separate conductivities. In the above example, as both branches are of the same resistance, viz., 10ω, the current will divide equally between them, and if four amperes are given off from the battery, two will pass along A branch, and two by B branch.

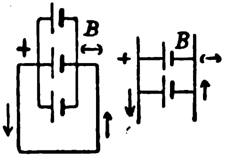

Fig. 32.

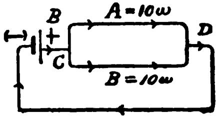

Fig. 33.

In Fig. 34 the resistances are not equal—one is 10 w., and the other is 20 w.; so, if three amperes are given off from the battery, two amperes will travel round A and one ampere round B, for $2 \times 10 = 20$, and $1 \times 20 = 20$, or current through A will be to current through

B as $\frac{1}{10}$ is to $\frac{1}{20}$; or as 2 : 1, for $\frac{2}{3}$ of the total current passes through A and $\frac{1}{3}$ through B. The joint resistance of A and B is less than the resistance of each branch taken singly. The joint conductivity will be the sum of the two separate conductivities. Suppose we again take $A = 10\omega$, and $B = 20\omega$, the joint conductivity is $\frac{1}{10} + \frac{1}{20} = \frac{3}{20}$, and on taking the reciprocal of $\frac{3}{20}$ we get $\frac{20}{3} = 6 \cdot 6\omega$, as the joint resistance.

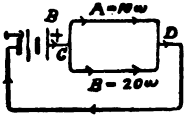

Fig. 34.

Suppose in Fig. 35 we have four wires bridging across the mains, every one of which $= 20\omega$ resistance, as their resistances are all equal the joint resistance will be $\frac{1}{4}$ of the resistance of a single branch. Their conductivity must be the reciprocal of their resistance, so—

$$\text{Conductivity} = \frac{1}{r1} + \frac{1}{r2} + \frac{1}{r3} + \frac{1}{r4}$$

$$= \frac{1}{20} + \frac{1}{20} + \frac{1}{20} + \frac{1}{20} = \frac{4}{20} \text{ mho.}$$

But resistance is the reciprocal of conductance; $\frac{4}{20} = \frac{20}{4} = 5\omega$, which is the total resistance of these four circuits arranged in parallel.

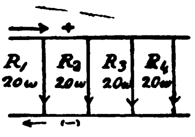

Fig. 35.

Thus, we say, that the total resistance is the reciprocal of the joint conductance, and this last is the sum of the conductivity of the separate branches.

If they were all arranged in series, the total resistance would be $20 \times 4 = 80\omega$, instead of 5ω.

When the different conductors or bridges are of different resistances (Fig. 36) we proceed as follows to find the total resistance—

$$\text{Conductance} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4},$$

but resistance is reciprocal of conductance.

$$\text{Resistance} = \frac{1}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\frac{1}{r_4}} = \frac{1}{\frac{1}{5}+\frac{1}{7}+\frac{1}{9}+\frac{1}{11}}$$

$$= \frac{1}{0{\cdot}2+0{\cdot}14+0{\cdot}11+0{\cdot}09} = \frac{1}{0{\cdot}54} = 1{\cdot}8\omega\,;$$

or, again, conductance

$$= \frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\frac{1}{r_4} = \frac{1}{5}+\frac{1}{7}+\frac{1}{9}+\frac{1}{11}\,;$$

bring this (by vulgar fractions) to a common denominator, then we get—

$$\frac{693+495+385+315}{3{,}465} = \frac{1{,}888}{3{,}465} \text{ conductance.}$$

Resistance is reciprocal of conductance—

$$\frac{3{,}465}{1{,}888} = 1{\cdot}8\omega \text{ same as before.}$$

Suppose that R_1, R_2 = the resistances, then $\frac{1}{R_1}$, $\frac{1}{R_2}$ represent their conductivities, and the united conductivity is $\frac{1}{R_1}+\frac{1}{R_2}$,

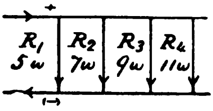

Fig. 36.

which equals $\frac{R_1+R_2}{R_1 R_2}$. This last is the joint conductivity. The joint resistance is the opposite—viz., $\frac{R_1 R_2}{R_1+R_2}$. We say that the joint resistance of any two conductors equals the product of those resistances divided by their sum.

Suppose there are three wires of different resistances, their joint conductivity is—

$$\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} = \frac{R_2 R_3 + R_1 R_3 + R_1 R_2}{R_1 R_2 R_3}$$

and the joint resistance is—

$$\frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2}.$$

Exercise.—Suppose there are two lamps, $L_1 = 100\omega$, and $L_2 = 150\omega$ resistance. When running, both are put in parallel with each other, and the pair are put in series with 150ω (L_3) lamp. What resistance is there in circuit?

Find first the joint resistance of L_1 and L_2, then add to that the resistance of L_3. By the above formula—

$$\frac{R_1\ R_2}{R_1+R_2}=\frac{100\times150}{100+150}=\frac{300}{5}=60\omega.$$

Now $60+150=210\omega=$ total resistance in circuit.

Exercise.—What power is absorbed in lighting 500 lamps, in parallel, of 200ω resistance each, at 100 volts? R in parallel

$$=\frac{R}{\text{No. of lamps}}=\frac{200}{500}=\frac{20}{50}\omega$$

and by Ohm's law—

$$C=\frac{E}{R}=\frac{100}{\frac{20}{50}}=100\times\frac{50}{20}=250 \text{ amperes.}$$

Then power absorbed

$$=C\times E=250\times100=25{,}000 \text{ w.}$$

$$=\frac{W}{\text{E.H.P.}}=\frac{25{,}000}{746}=33{\cdot}5 \text{ E.H.P.}$$

Exercise.—Ten incandescent lamps, having a R hot of 160ω each, are joined in parallel. What is their joint resistance?

$$\text{Conductance}=\frac{10}{160}.$$

Now— R = the reciprocal.

Then— $R=\frac{160}{10}=16\omega$

Series parallel arrangement (Fig. 37), where groups of resistances are joined in parallel, and then all the groups are joined in series. Here the total R is got by first finding the joint resistance of each group, and then taking the sum of these for the total resistance in circuit.

Resistances and Rheostats.—In the laboratory, wires of different degrees of resistance are often required, either as standards for comparing resistances or for varying the strength of the current in a circuit. *Resistance coils* (Fig. 38) are composed of platinoid or German-silver wires, wound spirally upon bobbins, fixed in sets in boxes for testing purposes. Each coil has a marked value, insulated with two coverings of silk wound double upon ebonite bobbins. The double winding is to eliminate any extra current involved in the coils, for, wound thus, the current flows in opposite directions, and they neutralise each other; then the bobbins are insulated with paraffin wax. Small resistances are formed of thick wire; higher resistances are made of fine wire. The individual resistance of a set of coils is generally the sum of the value to give any resistance from 1ω (ohm) to 10,000ω (ohms), such as 12ω, 10ω, 20ω, 100ω, 200ω, 500ω, 1,000ω, 3,000ω, 4,000ω, which enable any resistance to be quickly inserted or removed as required. Any of the coils, C, can be cut out of circuit between the first and last blocks, B, by inserting plugs, P, which short-circuit the coils between them. Thus, if all the plugs were inserted, no resistance would be in circuit, and if all the plugs were out, all the coils would be in circuit. The brass blocks are fastened down to an ebonite plate, which forms the top of the box which contains the coils. There are also terminals provided for attaching in circuit. Lord Kelvin's fine adjusting rheostat is used in the laboratory for putting in or taking out more or less resistance in the circuit. There is a

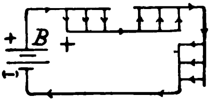

Fig. 37.

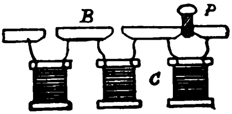

Fig. 38.

German-silver wire, which is guided between two rollers and laid upon them spirally by a travelling nut on a long screw spindle. This screw is turned by a handle, and as the wire is unwound off one cylinder, it is wound on the other one (of wood) which is in circuit. By turning the handle in a given direction, more or less resistance can be put in or taken out of circuit as desired.

Temporary resistances can be made by using a number of incandescent lamps arranged in series or parallel, also by using German-silver or iron wire, wound on a board and immersed in a tub of water, or by using two or more plates of gas carbon, in a non-metallic vessel filled with water, and lowering the resistance by adding a few drops of acid till the correct resistance is obtained.

Resistance coils are inserted into the shunt, or exciting circuits, of dynamos to regulate the e.m.f. at their terminals, according to the load. The coils used are mostly of German-silver or iron wire which has been galvanised; this is always left non-insulating, so that the heat generated is easily dissipated from the bare wire by radiation. These resistances are generally coiled in spirals on large frames, and placed somewhere in the dynamo room. In Fig. 39 the whole of the coils are joined in series. The left-hand terminal, T +, joins the left-hand spiral and the right-hand terminal. T (–) connects with the switch, which passes over five contacts, in this case. These contacts join the lower junctions of the spirals, and by altering the position of the switch the coils can be cut in or cut out of circuit in pairs as desired. When rheostats are used to keep the current, or the electromotive force of a dynamo constant, they are called regulators, as here shown. If the regulation is done by hand, they are called "hand regulators"; if done automatically, they are called "automatic regulators."

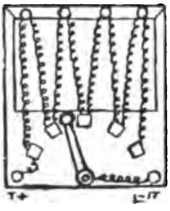

Fig. 39.

Water resistances are now often used for artificial loads from dynamos instead of spiral coils. They consist of two iron plates in a wooden tank, partly immersed in water, one being joined to the positive lead and one to the negative lead, and either, or both, are made adjustable, so as to vary the extent of immersion. The solution is composed of salt or sulphate of soda, and such resistances will deal with over 100 kw. for five or six hours without boiling, and they can be used for artificial loads at voltages up to 2,000.

CHAPTER V.

SOLENOID COILS, GALVANOMETERS, VOLTMETERS.

I. **Solenoid Coils.**—"If an insulated wire is coiled upon a cylindrical bobbin (as cotton thread is wound on a bobbin) so that several turns of wire are adjacent, and of two or three layers deep, such an arrangement is called a 'solenoid,' when the length of the coil is not small as compared with its diameter" (Jamieson's "Electricity and Magnetism").

Whenever a solenoid is put in circuit, and a current of electricity passed through its coils, lines of magnetic force or a magnetic field is set up, which runs through the coil parallel to its axis, and is called the inner field, the lines of which are of uniform density and straight in direction, and may be compared to a bundle of arrows enclosed in their sheath (Fig. 40). The outer field is much the same as that set up by an ordinary bar magnet, and can be demonstrated in the same way (see p. 12).

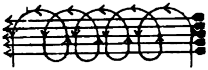

Fig. 40.

By the rule given in Munro and Jamieson's "Electrical Rules and Tables," we can easily find the poles of a solenoid and the direction of the current.

"1. By a compass needle ascertain the N. pole of the solenoid or core."

"2. Place the palm of the right hand on the solenoid, with outstretched thumb in the direction of the N. pole, or where the magnetic lines leave the solenoid or core. Then the direction of the current from the generator or battery, B (Fig. 41), flows as there shown."

"3. If we know the direction of the current in the winding, then by placing the right hand, as shown in Fig. 41, the thumb points in the direction of the N. pole of the solenoid, or core."

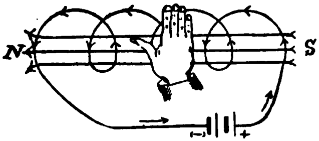

Fig. 41.

Iron offers an easier path for the lines of magnetic force to pass through than air does, so that they will alter their direction entirely in order to pass through iron, and by using iron we can lead the magnetic field or lines of force, and concentrate them where they are wanted to act; thus if an iron core be put inside the solenoid, then far more lines of force pass through it without leaking out between the convolutions and the numbers are increased. The strength of field can further be increased by increasing the strength of the current passing round the solenoid, or by increasing the number of turns of wire on the solenoid, or by both methods combined.

The solenoid coil, with its iron core, forms an electro-magnet, either end becomes a N. or a S. pole, according as the coil is wound in a right-handed or left-handed direction. If the solenoid be wound with insulated wire in such a way that the current passing round it travels in a clockwise direction (*i.e.*, in the same way as the hands of a clock), south-seeking polarity is developed at the entering end, and north-seeking polarity at the end of exit. If it be wound in the opposite direction, or as a left-handed helix, then the current will travel in an anti-clockwise direction around the solenoid, the entering end becomes a north pole, and the other a south pole.

The attractive force of an electro-magnet, or the pull which the core experiences inside the solenoid, from the attraction of the magnetic field can be easily shown. Fix a solenoid coil, NS, as in Fig. 42, having a current flowing round it, under a bar of soft iron, C, attached to the arm of a balance, B, and put weights, W, into the opposite scale pan, P, till they balance the attractive force of the current's field upon the iron. The nearer the bar is allowed to approach the solenoid, or even to enter inside, the stronger is the pull, and heavier weights are required in the pan to balance the bar. The strongest pull takes place when the bar is nearly midway between the ends of the solenoid, for there the greatest number of the magnetic lines of force are concentrated within by the bar, or it is in the strongest part of the field. If a brass solenoid was inserted it would have no effect on the field; as brass is non-magnetic, it would not be attracted. It is as well to bear in mind that whenever a current is passed round a coil, suspended vertically, it will suck into its interior a bar of soft iron (if free to move) by the attractive force set up, and hold this bar there so long as any current passes, and when the current is switched off, the bar will immediately fall out by its own weight, as there is no attractive force to hold it there any longer. Owing to this circumstance, it is possible to construct automatic switches and circuit-breakers, which are now used so much for electric-lighting and power-distribution purposes (see p. 144).

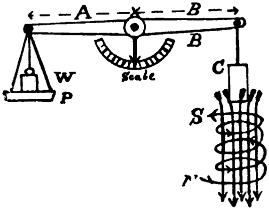

Fig. 42.

II. **Galvanometers.**—Whenever a magnetic needle, which is freely suspended, is at rest, it points in a N. to S. direction, or in a line with the magnetic meridian of the place. If we put this same needle between two wires arranged in series, which carry the same current, it deflects from the N. to S. position in proportion to the current's strength, and sets itself more or less at right angles to the direction of the current. If we now coil the wire in a few turns and make them surround the needle, we find the deflection of the needle is increased as the strength of field is increased, and every part of the current flowing round the needle tends to set up a magnetic field at the centre of the needle passing in the same direction. Oersted discovered that a current flowing parallel to the magnetic axis of a compass needle deflects it, and his apparatus is shown in Fig. 43, which demonstrates this fact. It consists of a copper wire bent as shown, and fixed by its ends to a wooden base, which connect with terminals. A central brass pillar supports a steel needle placed horizontally and pivoted, which is fixed midway between the two wires.

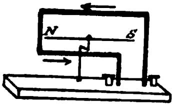

Fig. 43.

The Detector Galvanometer.—A simple form of this apparatus consists of a narrow elongated bobbin on which are wound 100 or more turns of, say, No. 20 cotton insulated wire, the ends being joined to terminals on the base. There is a paper scale divided accurately into divisions, and a magnetised steel needle is supported on a fine pin-point between the upper and lower layers of the coil (Fig. 44). When in circuit and a current flows, the needle is deflected, and by observing the number of degrees of deflection we get an idea of the strength of the current flowing, and this instrument is useful to detect the continuity of any conductor, short circuits, &c.

There are many different kinds of galvanometers, such as the *Astatic*, *Sine*, *Differential*, *Ballistic*, *Kelvin's mirror galvanometer*, *Deprez*, *D'Arsonval*, *permanent magnet and movable coil galvanometers;* but as these instruments are not used for measuring large currents given off for lighting purposes, but only weak currents used for testing in the laboratory, we will not say much about them; but the student should acquire a knowledge of these instruments from text-books dealing with them.

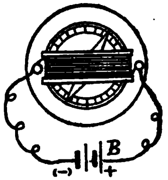

Fig: 44.

Tangent Galvanometer.—There is a single coil of thick wire of large diameter. In the centre is fixed a short, thick magnetic needle, with a light aluminium pointer, fixed to it at right angles, over a graduated scale. When a current passes round the coil the deflections of the needle are not proportional to the current strength, but to the tangents of the angle of deflection, and to find them we must refer to a table of tangents (see p. 62).

In the *sine galvanometer* the deflection produced is not proportional to the tangent of the angle, but to the sine of the angle, as the instrument and coil are moved about a vertical axis round a graduated scale, and we must turn to a table of sines to get the deflection.

The *astatic galvanometer* is a very sensitive instrument, and measures very weak currents.

The principle of this instrument consists in fixing two magnetic needles so that the N. pole of one is on the same side as the S. pole of the other one. This arrangement, besides producing an extra action on the upper needle of one side of the coil, tends considerably to counter-balance the attractive force of the earth's field, and this is what makes the instrument so sensitive. When at rest the needles do not point indifferently in any direction; were they equally magnetised and made perfectly astatic, they would do so, but as this cannot be done, the earth must exert some controlling force on them and so they keep more or less in a north to south direction (Fig. 45).

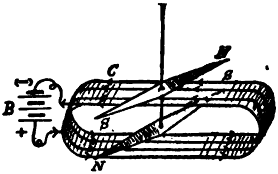

Fig. 45.

The *reflecting or moving coil galvanometer* is a delicate and accurate instrument for testing resistances, &c., in laboratory work. The principle depends on the fact that when a wire coil is suspended in a magnetic field and a current passed round it, the coil will swing round in the field till its magnetic field and that of the fixed field coincide, or till the lines of both fields run in the same direction when it comes to rest. There is the D'Arsonval Galvanometer as well as that of Lord Kelvin. This last instrument contains a coil of many thousand times of wire, the field is formed of three or four small magnets made from a magnetised watch-spring, and cemented on the back of the small mirror, which is suspended by a fibre or two of cocoon silk from a thumb screw. The mirror is made dead beat in action, *i.e.*, made so that it will quickly come to rest after being deflected. This is accomplished by making the mirror swing between two glass faces, which can be screwed up nearer or farther apart. When the mirror swings, the air inside the chamber reacts as a "couple" force on the mirror, and causes it to come to rest quickly. As the deflections of the mirror are very small, in order to render them visible a multiplying device is used in the form of a lamp with a graduated scale, painted white. The rays from the lamp to the mirror pass through a vertical slot in the frame which supports the scale, and are reflected back by the mirror on to the scale as a spot of light, and the deflections of this spot are proportional to the strength of the current passing through the galvanometer. A permanent magnet is fixed vertically over the galvanometer, and by means of this the little mirror, and consequently the spot of light, is brought back to zero on the scale

When using a galvanometer for testing purposes, if we find that the current flowing in the circuit is too strong for the galvanometer, owing to the needle being deflected up against the stops, in order to get a readable deflection we must allow only a portion of the current to pass through the galvanometer, and this is accomplished by inserting a resistance or shunt (see p. 40) between its terminals. Then the two currents will flow through the shunt and galvanometer in the inverse ratio of their resistances. Shunts are provided by which we can reduce the full current to any proportional part of it, say, $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ part, and the shunts used to do this have $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$ part of the galvanometer's resistance. By means of plugs we can insert any shunt we choose between the terminals of the galvanometer. With the use of a shunt the total resistance in circuit diminishes, and the current strength increases, so that a stronger current passes between the galvanometer and the shunt than the original current would be, and to make up for the decreased resistance we must add a corresponding resistance in the battery circuit, equal in value to the reduction in amount of the original resistance.

Formula to find the combined resistance of shunt and galvanometer is $\mathrm{G}\frac{1}{n-1}$, where the shunt's resistance is made $\frac{1}{n-1}$th part of that of the galvanometer's resistance. Formula for the combined compensatory resistance $= \mathrm{G}\frac{n-1}{n}$.

Exercise.—We require to reduce the sensitiveness of a galvanometer, the resistance which is 320 ω (G) to $\frac{1}{5}$ part. What will be the resistance of the shunt and compensating resistance?

Resistance of shunt—

$$\mathrm{G}\frac{1}{n-1} = 320 \times \frac{1}{5-1} = 80\omega \text{ (ohms)}.$$

Compensating resistance—

$$\mathrm{G}\frac{n-1}{n} = 320 \times \frac{5-1}{5} = 256\omega \text{ (ohms)}.$$

III. **Voltmeters** are instruments for recording the voltage, pressure, or difference of potential between the mains. Each is placed as a shunt to the main circuit, V, between the positive and negative conductors (Fig. 46). We may call them* galvanometers of practically constant resistance, and through them flow currents which are directly proportional to the impressed voltages. These instruments have a high resistance, such as from 15,000ω to 22,500ω. They are classified into the Electro-magnetic, the Electro-static, and the Hot-wire type.

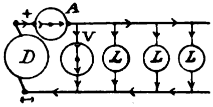

Fig. 46.

The Electro-magnetic Voltmeter.—Example, Weston's voltmeter. It consists of a steel horse-shoe permanent magnet, with soft iron pole-pieces, fixed to the polar limbs N. and S.

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* Electro-magnetic voltmeters only.

(Fig. 47). This forms a fixed uniform magnetic field in which a movable coil, C, is suspended by jewel points forming two centres. This coil is wound on a light aluminium frame, which surrounds a soft wrought-iron cylinder, or core, fixed, by brass strips, between the pole-pieces, and the use of which is to concentrate and intensify the magnetic field set up in the coil. The current passes in from the + terminal by one spring through the coil, and out again by the other spring to the – (negative) terminal. The springs are set in opposite directions, so that as one uncoils the other coils up, and the coil is brought back to zero, when it is moved by the current. The permanent magnetic field consists of the lines of force passing between the pole-pieces N. and S. of the permanent horse-shoe magnet. When a current flows through the small coil C, it endeavours to turn on its axis, so that its own lines of force, or magnetic field, coincide in direction with those of the fixed or permanent field. The deflections of the coil are proportional to the current passing through it, as the uniform magnetic field produced is proportional to the current flowing through it. The coil when moving takes the light aluminium pointer P (attached to its axis) along with it, and causes it to move across the scale Sc, and register the voltage. There is a semicircular looking-glass fixed on the instrument under the scale to prevent parallax error. The angles through which the coil moves are proportional to the stresses on the springs. The springs do three things. They keep the coil from turning too far; they admit the current; and bring back the coil to zero, when deflected. The principle of Weston's Ammeter is similar. These instruments are only used for measuring on continuous-current circuits.

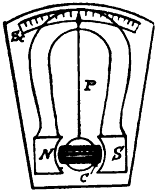

Fig. 47.

The Hot-wire Voltmeter.—Electro-magnetic or hot-wire voltmeters, connected to the secondaries of transformers, are much used in Germany. The Cardew voltmeter is a favourite one for testing purposes on board ship, as the replacing of a new wire is easily done by an average mechanic on board. It is dead-beat, and can be used for a continuous or alternating current. Its action depends on the fact that when a current passes through a wire it heats the wire in overcoming its resistance, and in heating it causes a lengthening of the wire (Fig. 48).

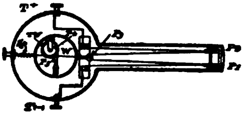

Fig. 48.

Current enters at the + terminal and passes along the wire round the pulley P_2, then round P_3, and after passing round P_1, leaves by the (–) terminal. If P_3 gets pulled then both P_1 and P_2 revolve. P_3 is composed of vulcanised fibre, and is pivoted in a brass strip, the other end of which joins a wire, W, which is fastened to a spiral spring, SP, the tension of which can be adjusted. The current heats the wire causing expansion, and the spring takes up the slack at the same time, exerting a pull on P_3. The wire, W, after it leaves the brass strip passes round a pulley, P_4, or drum, keyed on the same shaft as carries a tooth-wheel, TW. This latter gears with a pinion, P_5, on the pointer spindle, and this forms a multiplying arrangement, and renders the deflections so great that they may be easily observed on the scale of the instrument. Platinum silver wire 0·0025 inch diameter is used, as this has a high fusing point, is very flexible, and the co-efficient of temperature is uniform. The instrument is not perfect, as it absorbs some of the energy of the current when measuring voltage, and this is dissipated in heating the wire. The heat produced is proportional to the square of the current.

Electro-static Voltmeter.—This instrument was designed by Lord Kelvin, and is made by Messrs Kelvin & White, of Glasgow, and its action is based upon the fact that when two adjacent bodies are electrified to different potentials, mutual attraction is set up, and they tend to attract each other. This force of attraction becomes only of practical use when we deal with high voltages. As a rule, this attraction between bodies at D.P.'s is not very apparent, and is not fitted for practical use, except where we deal with high voltages, such as are used in electric lighting. There are one or two different types of this apparatus in use, but the principle is the same in all (Fig. 49). There are two or more pairs of fixed conductors, FV, and a movable one, MV, between them. The fixed conductors consist of two butterfly-shaped brass sheets, insulated from each other, placed parallel and metallically connected together. The movable conductor MV consists of one or more aluminium strips suspended by a fibre, or supported on a knife edge, and moving freely in a vertical plane between the two fixed plates. When at rest, weights keep the movable plate vertical. When a D.P. (difference of potential) is set up between the fixed and movable plates, attraction is set up and the latter tries to set itself inside the fixed plates, this tendency being counteracted by weights. The force of attraction is proportional to the square of the voltage. MV, to which the pointer is attached, comes to rest when gravity and electro-static attraction balance each other. The divisions on the graduated scale S represent voltages, and a larger range is got by varying the balance weights. The value in both of the e.m.f., which moves the pointers over the scale, depends on the weights used on the movable plate of the balance. When the lightest weight is used each division equals 50 volts. The next weight gives twice that D.P. While, when all three weights are used, one division equals 200 volts, so that the maximum, if there were sixty divisions, would be 200 × 60 = 12,000 volts. There is a dash-pot underneath containing oil, which renders the instrument "dead-beat."

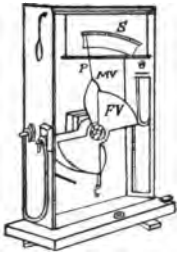

Fig. 49.

The Multicellular Voltmeter.—Another form of this instrument is the multicellular voltmeter, which is used in many generating stations. Here there are a large number of metallic vanes each moving between a pair of fixed conductors, as this method gives a great force of attraction. There are fifteen aluminium vanes placed horizontally and equidistant, fixed on a vertical spindle and all joined metallically together. A platino-iridium wire supports the spindle, so that the pointer stands at zero. The pointer is bent down over the curved vertical scale, which reads directly in volts. The fixed conductors are triangular brass plates all connected together, but insulated from the brass case of the instrument. When a D.P. is set up between the fixed and the movable conductor the attractive force causes the latter to place themselves inside the former, the spindle getting a rotary motion. The tension put on the suspending wire acts against the force of attraction, and the point at which the two forces balance is the position of the pointer, and this gives the D.P. in direct reading on the scale. In Fig. 50, which gives a diagrammatic representation of the way in which the voltmeter is joined up, D is the dynamo, FV the fixed vanes, and MV the movable vanes of the instrument, so they, being electro-static, allow absolutely no current to pass through them, so there is no liability to heating error, or to a waste of electrical energy, and for this reason one of these instruments may be permanently joined up in an electric circuit, and not increase the coal bill in any way. These voltmeters can be used for both alternating and continuous currents, and on alternating-current circuits they indicate the virtual volts (see p. 70). They are often used on high-pressure circuits in this country.

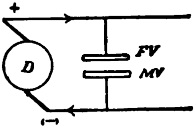

Fig. 50.

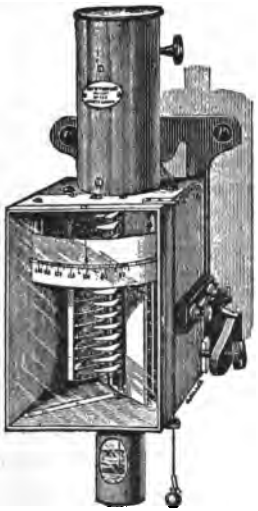

Fig. 51.

Fig. 51 is from a photo of the engine-room vertical pattern.

The Kelvin Recording Voltmeter for Direct Currents (Fig. 52).—It consists of a long solenoid coil, SC, giving an intense field, into which the upper part of a long soft-iron plunger, C, is entered. The plunger is suspended by a flexible cord from an aluminium sector, S*r*, and the movement is controlled by gravity. The pen P, with the inking arrangement, is suspended from the lower end of the plunger, and rests against a strip of paper, coiled round the drum D with sufficient pressure only to give good marking. The drum revolves by clockwork, and a permanent record of the voltage is got on the paper at the generating station. The drum is attached by a hinge to the base of the instrument, which enables it to be pulled outside the case when the paper requires to be changed. When pushed back against a stop it falls into its working position. The records run for from 12 to 24 hours.

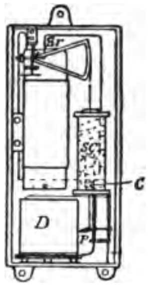

Fig. 52.

The Kelvin Patent Feeding Log.—This instrument records the current going out on a feeder and the pressure at the feeding point. This is a combination of the two instruments, a recording voltmeter and recording ammeter, giving two readings simultaneously upon a sheet of paper fixed on a drum revolving by clockwork.

In central stations a parallelling voltmeter is used when putting a dynamo in parallel with machines already running. Lord Kelvin's parallelling voltmeter is a handy instrument, and consists of two plugs, P, P′, which fit into plug-holes on the dynamo-board. M is a horseshoe permanent magnet, which forms the main field, and keeps the pivoted permanent magnet PM in zero, or mid-position (when no current flows) in the middle of the scale. Thus there are two scales, we may say, one on each side of zero, and reading in opposite directions, so that it is easy to tell the potential difference of the incoming dynamo and the bus-bars to which it is joined. The instrument is put into circuit when a dynamo is to be parallelled, and then removed after it has been put on the bus-bars (where all the dynamos deliver current). It records the voltage of any machine, and tells whether this corresponds to that of the bus-bars or not, to which the dynamo is to be parallelled, and also the correct time to close the main switch without causing any flicker on the lamps. One of the plugs P, P′, joins one side of the machine + or (–) and the other plug joins the + or (–) bus-bar (generally on the (–) side). When the voltage of the incoming dynamo equals that of the bus-bar the voltmeter registers zero, when the key K is pressed down. Next the main switch is closed, thus throwing the dynamo on to the bus-bars, and then the instrument is removed.

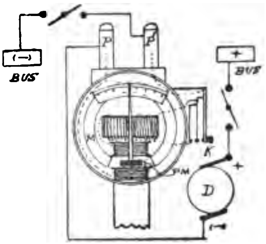

Fig. 53.

The general difference between a voltmeter and ammeter of the electro-magnetic type is that a voltmeter, V, is wound with "many" turns of fine wire, and is joined as a shunt between the mains (Fig. 46). While an ammeter, A, is joined in series in circuit, and takes all the current passing, and indicates the number of amperes passing; it is wound with a "few" turns of thick wire (Fig. 53).

CHAPTER VI.

MEASURING INSTRUMENTS.

Ammeters are instruments which record the amount of current passing to the lamps or motors from the source of supply. Their coils are of low resistance, and they are put in series in the circuit so that all the current passes through them. An electro-magnetic voltmeter might be made to register the current passing through it (if a different graduation were adopted on the scale) instead of the volts at its terminals, but the resistance of its coils would require to be small to give good results.

Ammeters are made usually direct reading in amperes.

The Schuckert Ammeter (Fig. 54).—The working parts are protected by a circular metal case with a glass front. It consists of a coil of insulated copper wire, sc^1, for weaker currents; but for stronger currents it consists of a single copper casting with helical sawcuts so as to let the current pass a few times round the needle; air is the only insulating material. Inside the coil, sc^1, on an axis parallel with its axis, but eccentrically placed, is pivoted a spindle which carries a soft iron core c, one side of which is flat and the other curved. One end of this spindle carries a light aluminium pointer, P, a small weight, w, keeps the pointer at zero when no current passes, but when in circuit, c, rotates, so that the curved part is drawn closer to the coil, sc^1, and comes to rest in the strongest part of the field through a distance which varies with the current strength, and when it touches the coil the pointer stands at the extreme position of the scale.

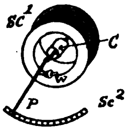

Fig. 54.

The principle of the Schuckert voltmeter is the same.

The Evershed Gravity Ammeter.—In this instrument a horizontal spindle, pivoted in agate bearings, carries a soft iron armature, and at one extremity a pointer. The armature only surrounds the spindle for half a diameter; by means of a counter-weight it is kept in a horizontal position when no current is passing. Surrounding this is a circular brass case, closed, except for a narrow slot to adjust the needle. Outside of this again is fixed a soft iron sleeve, split longitudinally. When a current passes through the coil of the instrument a magnetic field is produced in the iron sleeve, and a free field being set up between the two sides of the "split" the armature is attracted against the force of gravity into this field, and carries the pointer across the scale measuring the current strength by the number of deflections indicated thereon.

The scale plate is vertical, and the ammeter can be fixed against a switchboard; they may be made to read to any desired scale.

When electro-magnetic ammeters are used to measure alternating currents, and are calibrated for direct reading with continuous currents, the readings are slightly lower than the true value of the alternating current. This is due to eddy currents set up in the metal parts near the coil, and this error is corrected by permanently shunting the main ammeter by a small copper coil, which is over-wound with thin iron wire, to raise its self-induction to the proper value, and this is sufficient to reduce its shunting power, and cancel the error in the reading.

The principle of Evershed's voltmeter is similar.

The Kelvin Electro-magnetic Ammeter (Fig. 55) is one much used in electric generating stations, and is mounted on the main switchboard. These instruments register from 0·25 amp. up to 600 and 6,000 amps. There is a vertical slate base which carries a solenoid coil, SC, of copper plates, insulated with mica, and which has a very intense field. There is a balance frame, BA, suspended on knife edges; one end of this carries a soft iron wire plunger, WP, 20 c.m. long; underneath is hung a brass weight, W, to keep it vertical. The other end of the arm carries a counterpoise weight, CW. A platinum strip, P, acts as a pointer, and is attached to the centre of the balance arm; the free extremity passes over a graduated scale, sc^2, and indicates the strength of current passing through the solenoid coil. A dashpot, containing oil, is fixed below the plunger and renders the instrument "dead-beat" in action. Whenever a current passes through the coil it tends to suck the iron wire core upwards into the coil. This moves the balance arm, raising it slightly upwards; the pointer passes across the scale sc^2, and registers the amount of current passing through the ammeter.

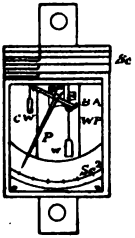

Fig. 55.

The Wattmeter is used, especially, for the purpose of measuring the true or actual power developed in an alternating current circuit, as the product of the amperes and volts, separately obtained (see p. 69), do not give the true power expended as in a continuous-current circuit. There are two kinds of this instrument—the moving coil dynamometer wattmeter and the induction wattmeter. Lord Kelvin's wattmeter belongs to the first type. It consists of a main fixed copper coil, bent into a figure of eight, joined in series with one of the mains. There are two movable fine wire shunt coils, arranged astatically, on a light aluminium frame, which rests upon knife edges. The resistance of each coil is 100ω. Current is led, by means of spiral springs, into the movable parts, only $\frac{1}{20}$ ampere is allowed to pass through the fine wire coils. When this instrument is put in circuit, the moment of the couple exerted between the fixed and moving coils measures the watts developed, and causes the moving coils to deflect against controlling springs through an angle, the amount of which is indicated by the pointer, on a graduated scale, and this measures the watts, or kilowatts, according to the graduation. This instrument can also be used on a continuous-current circuit.

The **Wheatstone Bridge** is formed on the principle of the ordinary balance. In Fig. 56 are two pans, suspended from a balance arm. A known weight, R, is suspended from the arm A, and the unknown weight, or substance to be weighed, X, is put in the other pan attached to the arm B. Then, when balance is got, the unknown weight X bears the same relation to the known weight R as the balance arm B does to the arm A, so $R \times A = B \times X$, and if $A = B$ then $R = X$. In the Wheatstone Bridge (see Fig. 57) there are four resistances, A, B, R, X, one of which, X, is unknown. All the rest are known. Join up as in the figure. A galvanometer is inserted between the junctions 1 and 2, a battery, B^1, is put between the terminals 3 and 4, and these junctions are kept at different potentials. To measure resistances such as that of a solenoid coil, the field-magnet, or armature of a dynamo, we vary A, B, and R, and adjust them by putting in or taking out plugs (Fig. 57) as required, till the absence of current passing through the galvanometer shows that the points 1 and 2 in the bridge are at the same potential or voltage, and the value of X can be calculated by the formula, for—

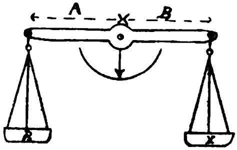

Fig. 56.

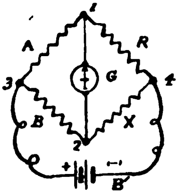

Fig. 57.

$$A : B :: R : X.$$

Suppose, when balance was got, the 1,000ω plug was removed from A, and the 10ω plug from B, and R was found to be 260ω; then—

$$A = 1{,}000\omega,\ B = 10\omega,\ R = 260\omega.$$

$$X = R\frac{b}{a} = \frac{260 \times 10}{1{,}000} = 2{\cdot}6\omega.$$

For high resistances the ratio of the arms used is mostly $A = 10\omega$ and $B = 1{,}000\omega$, and for low resistances $A = 100\omega$, $B = 10\omega$.

The Slide Metre Bridge (Fig. 58) is a form of Wheatstone Bridge in which, instead of removing plugs to vary the resistance to get equilibrium (on the galvanometer), this action is performed by moving a sliding contact, S, connected with the battery B along the wire AB, thus varying the ratio of the resistances A to B. The slide wire is 1 metre long ($39\frac{3}{8}$ inches), and

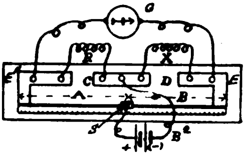

Fig. 58.

1·5 mm. diameter, stretched on a board parallel to a metre scale, graduated into divisions, and so fixed that the two ends of the wire are as near as possible opposite the extreme ends of the division 0 and 1,000, or 100, according to the number of divisions on the scale. The ends are soldered each to a broad thick copper band, EE^1, passing round each end of the graduated scale, which runs parallel to it on the side opposite the wire. The band is interrupted by two gaps, C, D, and has little resistance, as it is thick. Three terminal screws are fixed on the middle strip and two on each side of the others. X is the unknown resistance. Join the two adjacent ends of the middle and right-hand bands, while a known resistance, such as a resistance-box with coils, R, joins the adjacent ends of the other two. The battery B^2 joins the middle terminal of the central board at one end and the sliding contact on the other, so that B and X are in parallel with A and R. The galvanometer is joined across the end terminals. The sliding contact, when pressed down on the wire, makes contact with it, and allows of the exact point at which contact is made to be used on the scale. The battery and the galvanometer can be made to change places without affecting the result in any way. Then by the formula :—

$$\mathrm{A : B :: R : X}, \text{ but } \mathrm{X} = \mathrm{R}\frac{b}{a};$$

here, A = scale reading, $\mathrm{B} = 1{,}000 -$ scale reading, R = resistance put in circuit to get a balance, X = the unknown resistance. Suppose :—

$$\mathrm{R} = 10\omega, \quad \mathrm{B} = 1{,}000 - 500, \quad \mathrm{A} = 500 \text{ scale divisions.}$$

Then—
$$x = \mathrm{R}\frac{b}{a} = \frac{10 \times 500}{500} = 10\omega.$$

The Kelvin Balance (Fig. 59).—This instrument is one of Lord Kelvin's inventions for the measurement of current strength, and its action depends on the fact that attraction and repulsion occur between two adjacent conductors carrying currents, according to the direction in which the currents respectively flow. These instruments are only used in the laboratory for very accurate measurements, such as calibrating ammeters and voltmeters, &c., and are kept as standards for verifying ordinary instruments by. Standard sizes are made. Each is composed of four fixed coils, c^1, c^2, c^3, c^4, and a movable rectangle, MC. The first are fixed on a slate base. Each is composed of 10 copper strips whose ends are soldered together to form one conductor. The movable portion is capable of rocking through a small arc of a circle on knife edges. Current passes round the lower fixed conductor, and then divides at one of the supports of the upper movable rectangle. The two currents meet again at the other support, and pass on to the external circuit. From the direction of the arrows, it will be seen that on the right side the movable coil, MC, is repelled by c_1, and attracted by c^2; and on the left side, MC is attracted by c_8, and repelled by c_4: hence a force of attraction and repulsion is set up. Both forces thus tend to tilt the movable rectangle in the same direction, depressing the one side and elevating the other; but the rectangle is kept in a horizontal position by a sliding weight, which moves over a graduated scale, and the current strength, causing the deflection of the rectangle, is got from the value of the weight used, and its position on the scale when balance is obtained. When the switch handle H is put over, so that the switch is on contact V, the instrument measures volts, and when on contact W, it measures watts.

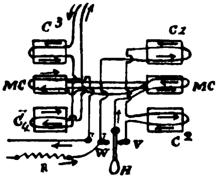

Fig. 59.

We do not take up electrical testing to any extent, as performed in the laboratory, for it is rather outside the scope of this work, but we will show by a simple method, in each case, how to test for resistance, voltage, current, and capacity.

Testing for Resistance (Fig. 60).—We have a conductor, a solenoid coil, or any other piece of apparatus, whose resistance we wish to find out. Join this up to a battery, B, and galvanometer, G, and allow a current to pass along it, the galvanometer needle will be deflected. Then, if we remove this and put a known resistance, such as a box of coils, in its place, we can get the same deflection as before by varying the amount of resistance in circuit by removing certain plugs from the box, and as we use the same battery the deflection of the galvanometer is the same. Hence, the resistance in the box obtained with balance must equal the unknown resistance.

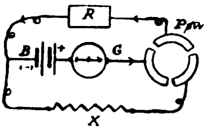

Fig. 60.

In Fig. 60 is shown a graphical representation of the method used. PSW is a three-way switch of three brass pieces, any two of which can be joined together by putting a brass plug in the holes between them, so that either R or X can be put in circuit as desired. Now if we use a tangent galvanometer, G, and a low-resistance battery, B, the currents, passed through R and X, can be compared by the deflections produced. We put R in circuit, and get, say, 50 divisions of deflection, and call this d_1. Next put X in circuit to get, say, 45 divisions of deflection, and call this d_2, the known resistance being 32ω. Now $d_1 = 50$, $d_2 = 45$, and the known resistance $= 32\omega$; but as the deflection in each case is proportional inversely to the resistance in circuit we say—

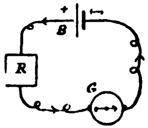

Fig. 61.

$$\text{tan. } d_2 : \text{tan. } d_1 :: 32\ x$$
$$\therefore \text{tan. } 45^\circ : \text{tan. } 50^\circ :: 32 : x$$
$$\text{or } 1{\cdot}000 : 1{\cdot}1918 :: 32 : 38{\cdot}13$$

(By referring to a table of natural tangents, we find that 1·0000 is the tan. of 45°, and 1·1918 is that of 50°.)

Testing for Voltage by the equal resistance method.—

Join up a standard Daniell cell (a well-made cell, in thorough working order, gives an e.m.f. of 1·07 volt) in circuit with a galvanometer and resistance R_1; note the deflection, call it d_1, say it is 60 divisions. Substitute the cell, or cells, of which the e.m.f. is to be determined, and change the resistance so that $R_2 = R_1$, or the total resistance put in circuit now is the same as before, and note the deflection; call it $d_2 = 345$ divisions, and let $E_2 =$ the e.m.f. of the unknown cell or cells, then—

$$E_2 = E_1 \frac{d_2}{d_1} \text{ volts.}$$

$$E_2 = 1{\cdot}07 \frac{345}{60} = 6{\cdot}15 \text{ volts.}$$

Testing for Current (Fig. 61).—Take a Daniell cell, join up to a tangent galvanometer, and with the magnet adjust the pointer till a deflection of 25 divisions is got with ·001 ampere, or 1 milliampere from the standard cell. Next remove the standard cell, and substitute for it the cell or cells whose current is to be determined, and note the second deflection. Say it is 59 tan. divisions, then—

$$\text{tan. } 25 : \text{tan. } 59 :: 1 \text{ milliampere} : P =$$
$$8{\cdot}4663 : 1{\cdot}6643 :: 1 \text{ milliampere} : x = 3{\cdot}569 \text{ milliamperes.}$$

To bring milliamperes to amperes divide by 1,000.

$$\frac{3{\cdot}569}{1{,}000} \doteq 0{\cdot}003569 \text{ ampere.}$$

To bring amperes to milliamperes, multiply by 1,000.

Capacity (see p. 71).—When a current is led into a condenser, or to anything which acts like a condenser—as an isolated sphere or a long cable—energy becomes stored up, and if the condenser be joined quickly in circuit with a galvanometer, owing to the static charges due to the condenser effects, the needle will swing from zero. This phenomenon is due to capacity, and we define the capacity of a conductor as "the quantity of electricity required to charge it to unit potential." Let K = capacity, Q = quantity, and V = potential, then—

$$K = \frac{Q}{V},\ Q = VK, \text{ and } V = \frac{Q}{K}.$$

A condenser consists of layers of tinfoil alternating with a dielectric composed of paraffin paper, glass, &c. All the alternate layers are joined together so as to form sets like the outside and inside coatings of a Leyden jar. When one coating is joined to one terminal of a battery, and the other to earth or to the other terminal of the battery, energy becomes stored up in it.

Muirhead's Standard Condenser has a capacity of $\frac{1}{3}$ microfarad (1 microfarad = 0·000001 farad).

Measuring Capacity by Direct Discharge (Fig. 62).—Charge standard condenser C^1 by a battery, B, for about 30 seconds, then discharge it through a ballistic galvanometer, G; note the throw d_1. Next charge the condenser to be measured, C_2, by the same battery, B, for 30 seconds, and discharge again through the ballistic galvanometer G (a very sensitive form of galvanometer), and again note the throw d_2.

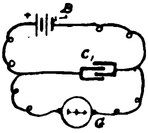

Fig. 62.

$$C_1 : C_2 :: d_1 : d_2$$

$$C_2 = C_1 \frac{d_2}{d_1}.$$

CHAPTER VII.

ALTERNATING CURRENTS.

DYNAMO-ELECTRIC MACHINES.

Alternating Currents and Alternators.—By alternating currents we mean those currents which, instead of flowing steadily in one direction around the circuit, are kept oscillating backwards and forwards at a high rate of frequency or cycles per second.

In Fig. 63 let the line *zz′* represent the zero line, and the line *abcde* the sine curve line of current and e.m.f. When the current line is above *zz′*, it shows that current flows in a positive direction, or from left to right, and when the current line is below *zz′*, it shows that current flows in a negative direction, or from right to left. The current and e.m.f. are thus continually rising and falling in value, and are represented by the line *abcde*.

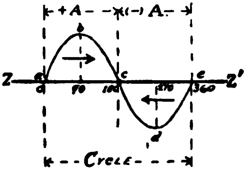

Fig. 63.

At *a* the current and e.m.f. have both zero value. They gradually rise to a positive maximum at *b*, fall through zero to a negative maximum at *d*, and up again to zero at *e*, thus completing a *cycle*, which means two complete alternations produced during one revolution of the loop of the rectangle. Each cycle is composed thus of two alternations, a positive alternation (+A), and a negative one (−A), which are shown by the curves *abc* and *cde*. *Alternation* strictly means a rise and fall of current in one direction. Sometimes it is used to indicate a complete reversal or cycle. *Frequency* means the rate of double alternations, or the number of cycles completed in one second. It is the reciprocal of the period, and is shown by the symbol $\sim$. If the periodic time $= T$, then $\sim = \frac{1}{T}$. If $P =$ the number of pairs of poles in the dynamo and $n =$ revolutions per minute, then $\sim = P\frac{n}{60}$ (60 to bring it to seconds), for frequency is measured by the product of the number of pairs of poles and the revolutions per second. *Phase:* When the current and e.m.f. rise and fall together, and reverse at the same time, they are in phase; if not, they are out of phase or step. *Amplitude* of C. or e.m.f. means the maximum distance between the zero line zz′ and the sine curve *abc* in a positive direction, or between zz′ and *cde* in a negative direction.

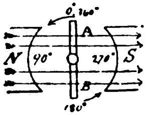

Fig. 64.

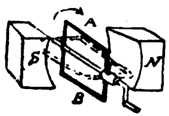

Fig. 65.

In Figs. 64 and 65 let N and S represent the poles of a dynamo, which is of the simplest possible type, and has a rectangular coil made up of two loops A and B, which in Fig. 64 are seen end-on only. The magnetic field or lines of force pass horizontally across throughout the whole of the area or space between the pole pieces. Starting at the N. pole they pass across the intervening space to the S. pole, and might be represented by an indefinite number of small threads placed close together, and passing across the space between the pole pieces.* When the rectangle AB is vertical, it embraces the maximum number of the lines of force, or, in other words, they pass through it. None are being cut by it, and consequently the e.m.f.'s induced in the loops A and B are zero. As A begins to rotate in the direction of the arrow, it commences to cut the lines of force, and the e.m.f. rises. A cuts more and more lines, and the e.m.f. again rises till A has arrived at 90°, or in the horizontal position, when it cuts the greatest possible number of lines of force, and the e.m.f. is a maximum, and in this position the rectangle embraces no lines of force. When this position is passed, the loop A begins to cut fewer and fewer lines of force, and the e.m.f. falls till it arrives at 180°, or is again vertical when the e.m.f. is zero, the coil A having made half a revolution. In the next half-revolution the coil A again cuts the same lines of force as before, but in the opposite way, as it cuts them in an upward direction, and the e.m.f. again rises (but in a negative sense) till the coil arrives at 270°; it again falls to zero when the coil arrives at 360° or has completed one revolution. Now, while the coil A was cutting all the lines of force in a downward direction, and setting up a positive e.m.f., the coil B was doing the same thing in an upward direction, and setting up a negative e.m.f. Thus, during one half-revolution, a current is induced which revolves round the rectangle in one direction, and if the rotation is continued on passing 180°, the current set up is in the opposite direction to the first one, but of the same strength, if the motion is uniform. A continuous rapid rotation of the rectangle sets up a series of currents alternating in direction, two in each revolution, the reversals taking place every time the coil is vertical, or has its plane at right angles to the lines of force. With the above rectangle the currents would continue to circulate round the coil and be of no use: we must use some device to lead them to the lamps in the external circuit. The rectangle might, as in Fig. 66, be mounted on a spindle, S, and insulated from it, with its two ends joined to two metal rings, R, R′, also insulated from the shaft and from each other, and bushes, B, B′, connecting with the external circuit, would rub on these rings and take off the currents. On driving round the rectangle and the rings on the shaft, the brushes,

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* *i.e.*, those that are being usefully cut to generate an e.m.f.

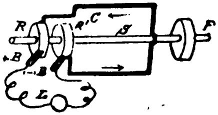

Fig. 66.

being fixed, carry away the currents as generated, to where they are wanted in the circuit.

In Fig. 67, let the rectangle coil 1*a* be an alternator coil which moves in the direction of the arrow, and is usefully cutting all the lines of force passing between the N and S poles, and is in the position of maximum e.m.f., current is in phase with the e.m.f., and the coil experiences its maximum torque or pull. In position 2*b* the pull is zero. Here the front loop of the coil is cutting lines of force passing in one direction, and the hind loop is cutting those passing in the opposite direction, and so the e.m.f. and current are zero. As the coil passes on to 3*c*, the current induced in it is in the opposite direction from current in 1*a*, as it cuts the lines of force which pass in the opposite direction, and the torque still opposes the motion, and is again at its maximum at 3*c*.

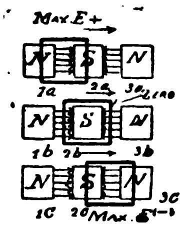

Fig. 67.

Self-Induction or *Inductance* is set up in the circuit. Whenever a change occurs in the current's strength an induced e.m.f. is produced which sets up an opposing current, and this tends to stop the original current which gives rise to it. This phenomenon arises owing to the alternating currents passing round helices—such as the windings of transformers, motors, and alternators—but it is scarcely apparent in straight conductors. Its effect is to cut down the current or stem it back. This is due to the back or counter-e.m.f. set up by the inductance. Suppose we put a choking-coil, CC, in series with a lamp, L, and a by-pass with a switch, K, so that the coil can be cut out of circuit (Fig. 68). This coil possesses inductance, but the rest of the circuit hardly any. When the switch is closed, to cut out the coil the lamp is fully lighted; then when the choking-coil is put in circuit, by opening the switch the lamp burns dimly, or not at all. Again, if a direct current be used, the insertion or cutting out of the choking-coil makes

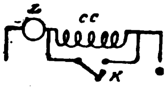

Fig. 68.

little difference in the lamp, as its resistance is small. This effect is due to the back e.m.f. produced in the choker reducing the current passing through the lamp. The effect of the self-induction is to cause the current to lag behind the impressed e.m.f.; it also retards the growth of current at starting, so that a short interval must elapse before the current attains its maximum (Fig. 69). It also lessens the amount of current passing. If there were no induction in the circuit the current would be in phase with the e.m.f., and they would rise and fall together; in which case, the watts would be found by *W = C × E; but as the current is not in phase with the impressed e.m.f., the watts produced are less according to the angle of phase difference, and this must be taken into account. To get the true power, or effective watts, use the formula—C × E × cos. ϕ = W.

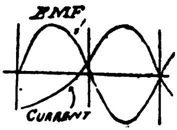

Fig. 69.

Exercise (taken from a laboratory test).—A small alternator, at 850 revolutions per minute, gives 7·2*a* at 90 volts. To find the power, use the above formula. Suppose the angle of lag is 45°. We turn to a table of cosines, and we find that the cosine of 45° is 0·7071.

$$C \times E \times \cos.\ \phi = W.$$

$$7{\cdot}2 \times 90 \times 0{\cdot}7071 = \frac{458{\cdot}2\text{W}}{746} = 0{\cdot}6 \text{ E.H.P.}$$

or fully half an electric horse-power.

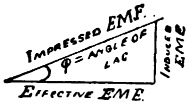

Fig. 70.

There is an angle of lag because the impressed volts in the circuit (see Fig. 70) are made up of two component parts, one in phase with the current as in continuous currents, and the other in quadrature, which is represented by a right-angled triangle. This counter or inductive e.m.f. varies with the frequency of the alternations, and iron cores inside solenoid coils increase it.

An alternating current not only meets with resistance as it passes along a circuit, but in addition there is inductive resistance, or the current divided into the inductive e.m.f. These two components are compounded at right angles, and the resultant is called *impedance*, and is shown in Fig. 71 as the hypotenuse of the triangle, so

---

* W. here is the apparent, or virtual watts only.

$$\text{inertia} = 2\pi n \text{L}s$$

$$(\text{impedance})^2 = (\text{inertia})^2 + (\text{resistance})^2$$

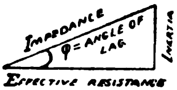

Fig. 71.

or—

$$\text{impedance} = \sqrt{4\pi^2 n^2 \text{L}s^2 + \text{R}^2}$$

Where $2\pi = 2 \times 3{\cdot}1416$

n = No. of alternations per second

$\text{L}s$ = coefficient of self-induction, say 0·002 henry

R = resistance in circuit.

So we say that alternating current—

$$\text{virtual C} = \frac{\text{E (impressed or virtual)}}{\text{impedance}}$$

Suppose in a circuit we have an alternating e.m.f. of 100 volts maximum value in one direction, and 100 volts maximum value in the other direction, the virtual value, or that indicated on an electro static voltmeter, will be 70·7 volts, or less than three-fourths of its maximum value. Suppose we have a current of 15 amperes maximum value in one direction, and 15 amperes maximum value in the other. This will have a virtual value of about 10·6 amperes. The reciprocal of $0{\cdot}707 = \frac{1}{{\cdot}707} = 1{\cdot}41$, so that if any virtual value of voltage or current be multiplied by this number, the product gives the approximate maximum value.

Exercise.—A Siemens dynamometer shows a current of 30 virtual amperes passing along per second. What actual quantity of current passes?

Since the maximum current = 1·41 of the virtual current—

$$30 \times 1{\cdot}41 = 42{\cdot}3 \text{ amperes per second.}$$

Exercise.—A cable (for continuous currents) was insulated to carry 500 volts. What is the highest virtual pressure of an alternating current for which this cable is fitted? Since E virtual = 0·707 of E maximum and E maximum = 500 volts,

$$\therefore \text{EV} = 500 \times 0{\cdot}707 = 353{\cdot}5 \text{ virtual volts.}$$

A virtual alternating voltage of 300 alternates between maxima of (300 × 1·41 = 423) 423 volts in either direction, and an alternating current of 40 amperes, between (40 × 1·41) 56 amperes in either direction.

Referring to Figs. 64 and 65 we see that one revolution of the rectangle causes the e.m.f. induced in it, as well as the current, to make two alternations—one in a positive direction, the other in a negative direction—and these form one period or cycle, and the rate of double alternations per second, or the number of cycles, is called a frequency, and this depends on the number of revolutions the coil makes in that time. Suppose it revolves 900 times in 1 minute, the frequency of the e.m.f. and current will be—

$$\frac{\text{revolutions}}{\text{seconds}} = \frac{900}{60} = 15.$$

Thus in a two-pole field the frequency equals the number of revolutions per second. In alternators the frequency is found by multiplying the revolutions per second by the number of pairs of poles.

Exercise.—An alternator has ten pairs of poles and runs at 300 revolutions per minute. Each coil passes through ten fields in every revolution—*i.e.*, there are ten complete reversals or waves of e.m.f. in each revolution. The frequency is—

$$\frac{\text{revolutions}}{\text{seconds}} = \frac{300}{60} = 5 \times 10 = 50 \backsim \text{(cycles).}$$

The frequency in this country varies from 25 ∽ to about 130 ∽, but the value is low for power-transmission purposes.

Capacity.—In every alternating-current circuit there is more or less of this, owing to the nearness of the two conductors to each other and to earth. The effect is as if a large, or several small condensers were put in circuit with the lamps, and into each, current was pumped during the rise of current, thus charging them, and on the decline of current they discharge into the circuit, and the effect of this discharge is to cause the main current to rise and fall in advance of the e.m.f. wave. Whereas we saw, with inductance in the circuit, the current wave followed that of the e.m.f. Now, it will be evident that if there be sufficient capacity in the circuit to balance or neutralise inductance, then the waves of current and e.m.f. will be in the same phase.

Choking Coils.—A bobbin of thick wire surrounds a laminated iron core, which is fixed or movable. If fixed, the inductance and reactance of the coil is fixed at a given frequency. If movable, the inductance and frequency can be increased or diminished by pushing the core into the bobbin, or pulling it out. This apparatus acts like a kind of elastic buffer between the dynamo and the lamps. During the rise of current, energy is stored in it, and prevented from reaching the lamps. During the decline of current, energy is given out which opposes the reversal of current, so that less again reaches the lamps. The use of a choking coil is to choke down or throttle the pressure in a circuit, and by its use a glow-lamp, or group of lamps, can be dimmed to any extent by cutting down the current, and so there is no energy consumed in heating the resistance, as with an ordinary resistance coil. They are used in theatres, churches, &c.: to dim the lights in the first, for stage effects; and in the second, during sermons, when little illumination is required.

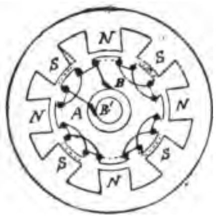

Fig. 72.

Alternators are divided into monophase, two-phase, and three-phase machines, according to the windings.

In a *monophase* as in all *alternators* the armature may be fixed and the poles rotate, or *vice versâ* (Fig. 72)—the effect produced is the same. The e.m.f. induced in the coils N and S is opposite, and they are so joined up that they cannot oppose each other, and this is done by reversing the connections of every alternate coil. This form of winding is called "concentrated" winding. The number of armature coils, A, and field coils are the same. All the coils are in series, and the two ends are joined to two insulated rings, B, B′, on the shaft, or they are joined by two, three, or more in parallel.

This machine is good for lighting purposes, but not for driving motors, as there is a dead point, and it will not start readily.

In an alternator, with revolving field magnets, and a fixed armature, connection is made between the exciting dynamo and the magnets by means of the brushes rubbing on two slip rings on the shaft. These convey current from the exciter to the field coils. No brushes or rings are required to collect the current generated, as the armature (being stationary) is directly joined up to the bus-bars.

A *two-phase alternator* (Fig. 73) has twice as many armature coils as there are field poles, and the simplest way to regard a two-phaser is to look upon it as having two armatures on the same shaft. The coils A are placed midway under the poles in one armature, and the coils B in the other are midway between the poles; but in an actual machine there are two sets of distinct windings on the same armature. In the A coils the e.m.f. is a maximum when the B coils are zero and they are 90° apart. There are two pairs of contact rings, or one ring is common to the two windings, thus making three rings only. Currents are collected by brushes, and led into separate cables. The second current is 90° behind the first. This machine, with the same carcase dimensions as a monophaser, gives 25 per cent. more output.

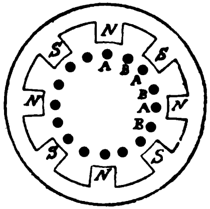

Fig. 73.

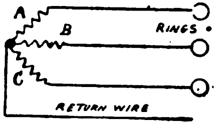

Fig. 74.

A *three-phase alternator* or *polyphase machine* has three sets of windings (Fig. 74) or coils, which we call A, B, and C. All the A coils are joined together, also all the B coils and the C coils. This arrangement is called the "*star coupling*," as there are three circuits radiating from the electrical centre of the star which is mostly earthed. One end of each coil passes to a slip ring on the shaft, if the armature rotates, but if it be stationary, they are joined to the 3-line wires direct, which transmit the three currents which are generated 120° apart in phase, or one-third of a period. When the lamps, motors, &c., cannot be so arranged as to equally load each of three phases, then a smaller section fourth,* or return wire, is used to connect all the lamps between it and one of the other 3-line wires. Each one of the conductors successively serves as a return for the other two, the algebraic sum of the currents in the system being zero. This machine is used for power distribution purposes mostly, and also for lighting; the advantage is that in this system the total weight of copper for transmitting current for a given power is only about one-fourth of what it would be with a single-phaser. In this class of machine the armature is generally fixed and the poles rotate.

It is possible to make a three-phase machine become a single-phase machine by using the winding of one of the three-phases alone; or by coupling two of the phase windings in series, or again by coupling all the windings in series, and then the output would be greatest, and be about two-thirds of the three-phase output.

Alternators are divided structurally into four types, according to the arrangement of their armature coils.

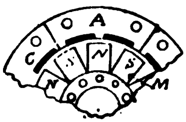

Fig. 75.

(*a*) *Face coil armature* (Fig. 75) with rotating field magnets. There is an outer flat ring of laminated iron; this forms the fixed armature A, on the inner face of which are placed in slots in the iron core the coils C. Inside this ring the magnets M, mounted on the shaft, revolve, and are arranged radially, with the poles projecting towards the armature coils, and are so wound as to be alternately of opposite polarity.

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* This wire is joined up to the middle of the three-wire star system of winding.

(*b*) *Tunnel-wound armature* is similar to the last example, but, instead of slots, holes are drilled through the armature, and the winding is put through these holes, and the conductors are said to be "buried."

(*c*) The *radial coil armature* contains no iron in the core; sometimes it revolves and sometimes it is fixed, but, in either case, the coils are flat and fixed edgewise. What is known as the "copper type" alternator of Messrs Ferranti has an armature of this kind, which revolves, while the field magnets are stationary; the poles being alternately N. and S. with facing poles of opposite polarity.

(*d*) The *drum wound armature* is like that of a continuous-current dynamo: there are slots or holes through which the conductors pass.

The *inductor alternator* has fixed armature coils and fixed field magnet windings. The field poles, or inductor poles, are the only parts which rotate. For a full description of these machines the student must consult an advanced text-book.

Alternating Currents are now much used for long-distance transmission of energy; one reason being that the higher the working voltage and the smaller the current transmitted, the greater is the efficiency of the system. With alternators we can use high pressures. Generators are now designed to give from 2,000 to 3,000 volts for small outputs, and from 3,000 to 5,000 volts for large machines. Modern machines do not much exceed 6,000 volts, and at either end of the line, or at both, we can use transformers to increase or reduce the voltage in any desired ratio.

Alternators, as a rule, are unable to excite their own field magnets, unless they belong to what is known as separate coil alternators (in which current from some of the armature coils, after being rectified, or made continuous, is used to excite the field magnets, see p. 185), because, though magnetism is set up, with every alternation of current it is reversed, and no permanent magnetisation is produced: hence each machine has its field magnets excited by a small continuous-current dynamo mounted direct on its own shaft or belt driven by a steam-engine of its own. These exciting dynamos are mostly shunt-wound machines. This form of alternator is called a separately excited machine.

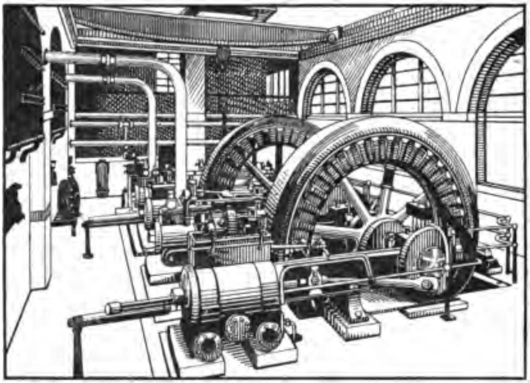

Fig. 76.

In Fig. 76 are shown two of Siemens' fly-wheel alternators in the power station at Ayr. One is still running. It has revolving fields and a fixed armature. It is of 100 kw. capacity, giving 50 amperes, at 200 volts, at 60 cycles per second. The horizontal coupled compound-condensing engine gives out 175 I.H.P., and drives the alternator direct.

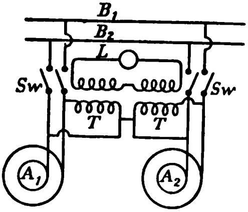

Fig. 77.

The Synchroniser. — When alternators are run together so that their outputs may be combined, the machines must run in synchronism, *i.e.*, their speeds must be such that their frequencies are the same. They must run in "phase" or "in step," *i.e.*, they must all give a maximum impulse of the same sign to the same bus-bar at the same instant. When alternators run in parallel, if one should slow up, the other immediately pumps current into it, hurrying it up to synchronism. A synchroniser mostly consists of special transformers and a lamp, mounted on the switchboard (Fig. 77). The primaries are joined, one to the loaded and one to the idle alternator, with their secondary coils in series through a lamp. If the secondary coils are cross-connected, the lamp, L, lights to full brilliance at synchronism; if in straight series, the lamp is dark at synchronism.

To join up the idle machine A_2, excite the fields till at full speed the voltmeter shows the bus-bar pressure, join it to the synchroniser, find out when A_1 and A_2 are in step, then throw A_2 on to the bus-bars, B_1, B_2. Next increase the engine speed till A_2 takes its share of the load. To disconnect, reduce speed; then open main switch, *sw*, and stop the machine. Messrs Everett & Edgcombe, of London, now make a rotary synchroniser (Fig. 78), consisting of a dial with revolving hands, and this shows if the incoming alternator runs too fast or too slow, or if out of step at the moment of switching in. It consists of two windings—a stator and a rotor—supplied by alternating current from two sources. The stator joins the bus-bars, and the rotor the terminals of the alternator to be parallelled. A movable vane obscures either a red or green lamp through an opening in the dial, and this can be seen by the engine driver, and he knows which of the engines is running too fast or too slow. If the frequencies are the same, both fields revolve at same speed, and the pointer is stationary. A synchroniser lamp, L, on the top tells which machine is out of step. Dial equals 8 inches diameter.

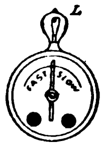

Fig. 78.

CHAPTER VIII.

CONTINUOUS-CURRENT DYNAMOS.

ALTERNATING current is not suitable for depositing metals in electrolytic processes, for charging storage batteries, and magnetising field magnets. Every alternator and dynamo generates alternating currents, but, in the latter machine, by means of a special mechanism, called the "commutator" current, after being generated, is made to flow in one direction in the external circuit, and thus becomes "direct" or "continuous." With a continuous current a dynamo is able to excite its own field magnets, and does not require an auxiliary dynamo or exciter as an alternator does.

In Figs. 65 and 66 it was shown that the direction of the current remained the same during the first half-revolution of the rectangle coil, and at the end of that time the reversal in direction took place. Now, if just at the instant when reversal took place, the positions of the two brushes were suddenly interchanged, then the current generated during the second half-revolution would flow in the same direction as the preceding current did, though generated in the reverse direction. It is utterly impossible to interchange the brushes, but the same result is got by modifying the rings on which the brushes rub. Instead of two collecting rings, one ring only is used, which is split lengthwise into two halves, C (Fig. 79), insulated one from the other. Each end of the rotating rectangle RC is joined to one segment, and these segments form the commutator.

When the rectangle is vertical, reversal takes place; if, then, the ends of the coil in contact with their respective brushes are reversed, and if the rectangle be uniformly rotated, a succession of short currents pass through the external circuit. The current rises and falls in the same way as an alternating current; but instead of developing a negative potential in the external circuit, it is commutated into an external positive one (Fig. 80).

M. Gramme, of Paris, patented the dynamo in 1870 known as the "*Gramme" dynamo.* In 1872 the permanent magnets of his original machine were replaced by electro-magnets, as Varley had made the first self-exciting dynamo in 1866 (Sir Charles Wheatstone and Dr Werner Siemens discovered simultaneously the principle of the dynamo). In London, in 1873, Gramme lit the clock-tower in the Houses of Parliament, London, by one of his dynamos, and in 1878 another one worked a Jablochkoff candle at the Avenue de l'Opera, Paris.

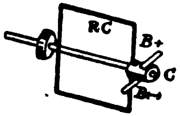

Fig. 79.

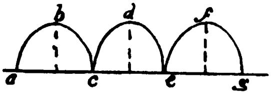

Fig. 80.

Edison's dynamo, or *Faradic machine*, consisted of two long upright columns wound with wire; the base formed the magnetic poles, which was called the "field of force magnetic." Revolving on an axle between the poles was a wooden armature wound with fine iron wire. This machine was improved by the late Dr John Hopkinson, who shortened and increased the area of the field magnets, and substituted an iron armature with copper wire, thereby greatly increasing the efficiency. This dynamo is now known as the Edison-Hopkinson dynamo.

A continuous-current dynamo consists (Fig. 81) of four main parts—viz., the field magnets M, M^1, and brushes B, B, which are fixed, the armature A and commutator C, which revolve. Currents are set up by electro-magnetic induction in the armature coils, revolving between the pole-pieces P, and these are so joined up that the single-current impulses are added together; the coils also connect with the commutator upon which the brushes rub, and carry current to the external circuit. The field magnets produce the poles which form the starting point of the whole process. The magnets are joined together by the yoke Y, which completes the magnetic circuit.

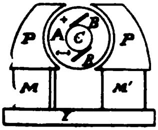

Fig. 81.

The *armature* is the part in which, by the action of the magnetic flux, e.m.f.'s are developed. Siemens' armature, with a shuttle-shaped core, is one of the earliest types. There is only one coil of cotton-covered wire wound in the grooves, the ends being joined, one to each segment of a two-part commutator. Only very small toy machines are now constructed with these armatures; mostly they are solid, but sometimes laminated, and to get any good results they must be driven at very high speeds, about 2,000 revolutions per minute (Fig. 82), and even then the current and e.m.f. are very unsteady. A step in advance of this is the Hefner Alteneck armature (Fig. 83), where there are two coils, and when the one is at zero position, the other one is most active, and the e.m.f. and current are much more steady. There is a four-part commutator, and the coils being at right angles there are no dead points. The more coils put on, the steadier is the e.m.f. and current. If a *shuttle* armature be quickly rotated in a magnetic field for a short time it gets hot, and the longer it is rotated the hotter it gets. This is due to *Eddy* or *Foucault* currents being set up in the iron at right angles to the lines of force, and these circulate lengthwise in the core and do injury

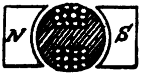

Fig. 82.

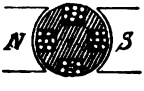

Fig. 83.

(Fig. 84). We cannot prevent the formation of these currents, but we can obstruct their path through the iron by making the core laminated instead of having it solid, and in this way it is still continuous in the direction in which the lines of force pass through it from the field magnets, but discontinued in the direction in which the eddy currents flow, *i.e.*, at right angles to the lines of force. Modern dynamos have their armatures built up of thin charcoal-iron discs (Fig. 85) threaded on a steel spindle, then keyed on and perfectly balanced. Each is insulated from the next by shellac varnish, thin paper, or mica, to prevent, to some extent, the formation of eddy currents. In large dynamos, for the same reason, many makers use laminated conductors, or conductors formed of stranded copper wire.

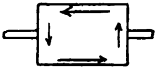

Fig. 84.

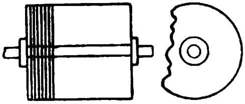

Fig. 85.

The drum armature (Fig. 86), in which the coils are arranged on the surface of an iron cylinder or drum, is overwound with conductors which pass along the outer surface and go around it axially. It is a common practice now to wind the conductors in separate convolutions around the core by hand, beating them into place with wooden mallets and wedges. In order to allow of a coil, if damaged, being easily removed and replaced, a patented system of winding is used by some makers, by which each separate coil is always entirely distinct from and independent of the other coils. To allow of this being done, each coil, previous to being fixed on the armature core, is wound to exact shape required on a "*former*"—an apparatus made of wood or metal, so shaped that the coils when wound upon it take the exact form required for their arrangement

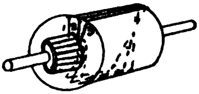

Fig. 86.

on the core. The whole of the coils required for any given size of armature are formed on this kind of apparatus, and so their interchangeability is at all times secured. After being formed the coil is insulated with tape, varnished, and tested previous to being fixed on the core. Coils thus pass all round the armature till it is covered. Here all the conductors are usefully employed cutting the lines of force passing through the armature, only the end connections are idle, and no counter-e.m.f. is ever generated.

The ring armature (Fig. 87) consists of a number of charcoal-iron flat rings, bolted together, and fitted to the radial arms of a gun-metal spider keyed on the steel shaft. The extremities of the arms fit into notches in the discs. The coils C may be of rectangular bars; they are wound over the armature round the ring till it is covered. The end of each coil is joined to the beginning of the next one, and at each junction the two ends join a commutator bar, CS. There are as many bars as there are coils. When all the coils are joined up with each other all round the armature, it is called a "closed-coil" armature. Example: Siemens, Gramme armatures.

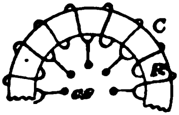

Fig. 87.

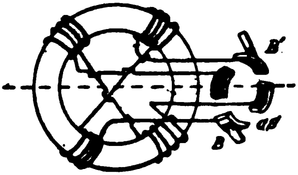

Fig. 88.

Sometimes the coils are arranged in pairs on the opposite sides of the ring (Fig. 88). Each pair connects to opposite commutator segments, CS, on which the bushes B, B′, rub. This type is called the "open-coil" armature. Example: Brush and Thomson-Houston arc-light machines.

The Disc Armature.—Here the conductors are arranged in disc form. The plane is perpendicular to the shaft, as the disc revolves in a narrow slot between the pole-pieces. There is no iron core.

When an armature revolves (Fig. 89) between the magnet poles, stationary poles are set up in the revolving iron, and the effect produced is the same as if the coils revolved and the ring or drum was stationary. We look at the core as consisting of two permanent magnets with like poles adjacent. Suppose the coils rotate in the direction of the arrow; coil 1 is approaching a S. pole (on the ring). By Lenz's law the induced current must resist the motion which generates it, and so the coil will present a S. pole to the S. pole on the ring. By the same law, coil 2 is leaving a S. pole, and must have a N. pole induced in it in order to resist the motion; also coil 3 must have a N. pole and coil 4 a S. pole. It will be seen that current flows the same way in all the coils on one side of the vertical line through the armature, and in the opposite way in all the coils on the other side of this line, and, if the brushes are placed at B, B′, a continuous current flows in the external circuit as long as the armature is revolving.

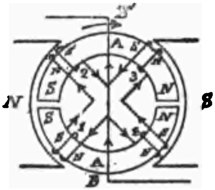

Fig. 89.

The drum armature is more efficient than the ring in dynamos of the same size; but they are not so strong mechanically, and require good ventilation. The armature conductors are of copper. For small currents they are circular in section, and wound in two or more layers on the surface of the core. For heavy currents they are always of rectangular section to economise space, and always insulated with silk or a double layer of cotton braided on, and varnished with shellac or rubber varnish. As already mentioned, large dynamos have their armature conductors made up of strands of copper wire. The separate strands are varnished, insulated from each other, and then compressed into a bar of rectangular section. These conductors not only prevent eddy currents to some extent; but are also said to increase the efficiency of large machines by about 4 per cent.

The resistance of an armature is only half that of the total amount of wire upon it.

The induced e.m.f. is proportional to the number of active conductors joined in series, and each coil may have one turn or many turns. Suppose there are 60 coils on the armature, and each coil generates 2 volts, the whole e.m.f. developed $= 2 \times 30 = 60$ volts, for the total e.m.f. = the number of active conductors round one-half of the armature (the two halves are in parallel) multiplied by the average e.m.f. set up in one coil during half of a revolution. The voltage depends on (1) the number of magnetic lines of force, or the density of the magnetic field in which the armature revolves, this $= \text{M}a$; (2) the number of conducting wires, or convolutions, in the armature $= \text{T}aw$; (3) the speed of rotation, n = number of revolutions per minute, therefore $\frac{n}{60}$ = revolutions per second—

$$\frac{\text{e.m.f.} = \text{M}a \times \text{T}aw \times \frac{n}{60}}{10^8}$$

(to get absolute volts). Suppose a dynamo has 4,000,000 magnetic lines fixed through its armature. There are 150 convolutions on it, and speed = 1,040 revolutions per minute. What is the voltage?

$$\text{E}a = \frac{\text{M}a \times \text{T}aw \times n}{60 \times 10^8} = \frac{4{,}000{,}000 \times 150 \times 1{,}040}{60 \times 100{,}000{,}000} = 104 \text{ volts.}$$

(*Note.*—10^8 means 10 multiplied into the power of 8, or multiplied 8 times by itself, which is 100,000,000.)

The current given by a dynamo depends upon its e.m.f., the resistance of the internal circuit (armature, field magnets) + the resistance in the external circuit on which it works, as any counter or opposing e.m.f. in the circuit, as storage batteries being charged, or motors being run. Let E = the dynamo's e.m.f., e = counter-e.m.f. of the circuit, R = internal resistance of dynamo, r = resistance of external circuit, C = current flowing in amperes. Then, if the external circuit has no counter-e.m.f. as lighting incandescent lamps, only—

$$C = \frac{E}{R + r} \text{ amperes.}$$

If there is a storage battery being charged, or motors being run, then the opposing e.m.f. $= e$,

$$C = \frac{E - e}{R + r}.$$

The commutator (Fig. 90) of an ordinary dynamo varies very much from the elementary two-part commutator, and is much more complicated. It consists of a number of segments, B, of hard-drawn copper, insulated from each other by strips of mica. Square clamping notches, N, are turned on the ends of the bars, into which fit grooved rings of hard vulcanised fibre, F. A gun-metal sleeve, S, having a cone turned on one end, slides over the shaft S*t*, and is prevented from turning by means of a pin. A nut, N′, screws into one end of the brush, and over this slides a loose coned collar, C. Two gun-metal cones fitting into grooves in the fibre rings, are forced together by the nut, N′, on the end of the sleeve, and bind all the segments firmly together. Lugs, L, make electrical connection from the commutator segments to the coils of the armature; they are formed of copper strips. A saw-cut is made in one end of each segment, and one end of the lug is soldered into this. The other end is soldered to the projecting end of the armature coil. Air forms the insulation between the sleeve and the commutator. The peripheral speed of modern commutators = 1,500 feet to 2,500 feet per minute, and centrifugal force is apt to cause the various parts to fly apart unless the commutator is well made as a whole. The commutator should be of such a length that the brushes are staggered, *i.e.*, both brushes

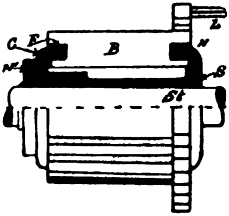

Fig. 90.

should not rub on the same annular path, but rather overlap each other, as this prevents grooving. Multipolar dynamos are provided with very large commutators, and have carbon brushes.

The brushes lead the currents away from the commutator to the external circuit. They consist of flat, tough copper strips; but carbon brushes are now much used in modern dynamos and motors. The brushes are fixed in adjustable holders, which are carried by horizontal arms, projecting from a gun-metal rocking lever, which, by means of an insulated handle, can be rotated in either direction around the axis of the shaft, and so the position of the brushes can be altered to suit requirements. Spiral springs, with adjusting screws, vary the pressure of the brushes on the commutator. Brushes must be set diametrically opposite each other, and must be adjusted till a sparkless position is got. This is called "the lead," and in all dynamos the lead is *forward*, or in the direction of rotation. In motors it is *backwards*. The commutator may be rubbed over with a little vaseline now and again, but never oiled. Self-lubricating brushes, having the compound rubbed into the gauze, are now being put on the market. The shaft bearings are mostly made of phosphor bronze, and are self-oiling, by means of an automatic revolving ring inside.

The field magnets are composed of wrought iron, cast iron, or even cast steel; but as the permeability of wrought iron is greater than cast iron, the parts of the field magnets on which the exciting coils are wound are of this material; the pole-pieces and yoke of cast iron are bolted to the wrought-iron limbs. The *Salient pole* field magnet is often met with; here there is only one magnetising coil, which is wound on a wrought-iron yoke, bolted to cast-iron pole-pieces. Another form often used has two exciting coils with wrought-iron limbs, of rectangular section, bolted to the bedplate which forms the yoke, the magnetising coils being wound on bobbins and slipped over the limbs. The *Overtype* form has the armature above the field coils and yoke. The *Undertype* has the armature below the field coils and yoke; but as the field magnet is supported on a cast-iron bedplate, it is necessary to magnetically separate its pole-pieces from it, or they will be magnetically short-circuited. *Consequent Pole Field Magnets.* Example: "Manchester" dynamo, which is a double magnet, the exciting coils being wound on what we regard as the magnet yokes, two similar poles being produced in each pole-piece. *Multipolar Field Magnets.*—In this machine there is a ring of iron with the magnets and pole-pieces projecting radially inwards, the wrought-iron magnet cores being bolted on the wrought-iron pole-pieces, and the magnetising coils wound so that consequent poles of alternate polarity are produced around the armature (Fig. 91).

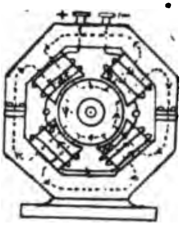

Fig. 91.

Dynamos are called Separately-excited, Series, Shunt, and Compound-wound machines, according to the method used in connecting them. A *separately-excited dynamo* has the field magnets magnetised from some external source, and is not much used. *The series dynamo* (Fig. 92) has the field-magnet coils SC included in the main circuits, and they are magnetised by the whole of the current generated in the armature A. This dynamo gives the strongest current and the most intense field when the terminals are short-circuited by a piece of wire. The polarity is apt to get reversed, and it is never used for charging purposes, because it runs as a motor in the opposite direction to what it does as a dynamo, and if it was used for charging, and a breakdown occurred in the engine, the opposing e.m.f. from the cells would, if strong enough, run it as a motor, along with the engine, and damage the machine. It is used mostly for running arc lamps.

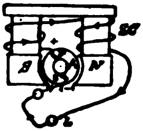

Fig. 92.

The Shunt Dynamo (Fig. 94).—The field-magnet coils SC form a shunt circuit to the main circuit MC, and are magnetised by only a part of the current generated. The proportion of current that passes round the external circuit and the shunt coils depends entirely upon the relative resistances of these circuits. The armature resistance must be low, and that of the field magnets relatively high. This machine is used for lighting incandescent lamps and charging storage batteries. It runs the same way whether used as a dynamo or a motor. A regulating rheostat is put in the shunt coil circuit to regulate the e.m.f. by inserting, or removing more or less resistance, to give a constant potential at the brushes. If the brushes be short-circuited by a thick wire, the low resistance of this path will cause all the current to pass round this way, and none will flow through the shunt coils; so very soon the dynamo will cease to generate current, as the magnets become demagnetised. The potential at the brushes decreases directly as the load increases.

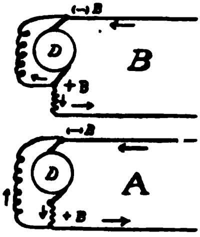

Fig. 98.

The Compound Dynamo.—We may regard this as a shunt machine and a series machine combined in one. Besides the shunt coils, there is added to it round the magnets a few turns of wire in series with the external circuit. The series coil is sometimes wound outside, and sometimes inside the shunt coil. The dynamo may be "compounded" to maintain a constant e.m.f. at the terminals under varying loads, or "over-compounded" to keep a constant e.m.f. at the central point of distribution to compensate for loss in the feeders. The series coils are proportioned to increase the strength of field in proportion to the loss in the shunt winding, and so the voltage at the brushes remains constant for any load within the working limits. There are two forms: the long shunt and the short shunt. The long shunt (Fig. 93A) has the coils joined up between one brush and the end of the series coil most remote from the brush. The short shunt (Fig. 93B) is connected from brush to brush, called the "over-compounded dynamo."

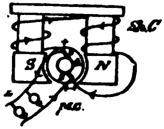

Fig. 94.

Continuous-current dynamos are divided into constant current and constant potential machines. The *first* are used for lighting arc lamps in series, as all the lamps take the same current, and the voltage varies with the number of lamps in circuit. The *second* are for incandescent lighting, where a constant voltage must be maintained at the lamp terminals, the current varying with the number of lamps in circuit. A dynamo is unable to convert into electrical energy the whole of the brake horse-power or mechanical power put into it from the engine. A certain quantity is lost in friction; therefore the input or driving-power must always be greater than the output, or useful electrical horse-power given out. The *efficiency of a dynamo*, of which the symbol is η, is of three kinds: the mechanical η, the electrical η, and the commercial η—

$$\text{Mechanical } \eta \text{ in per cent.} = \frac{\text{total E.H.P. developed} \times 100}{\text{total B.H.P. put in}}.$$

A dynamo requires 100 B.H.P. to run it when generating 60,000 w. What is the mechanical η?

$$\eta = \frac{60{,}000 \times 100}{100 \times 746} = \frac{6{,}000{,}000}{74{,}600} = 80{\cdot}4 \text{ per cent.}$$

This means the power of the dynamo to convert mechanical into electrical energy.

$$\text{Electrical } \eta \text{ in per cent.} = \frac{\text{E.H.P. to external circuit} \times 100}{\text{total E.H.P. generated}}.$$

A dynamo generates 85,000 w., of which 400 amperes at 200 volts go the external circuit. What is the electrical η?

$$\eta = \frac{400 \times 200 \times 100}{85{,}000} = 94 \text{ per cent.}$$

This means the power of the dynamo to convert the total E.H.P. generated into useful work in the external circuit.

$$\text{Commercial } \eta \text{ in per cent.} = \frac{\text{E.H.P. given to outer circuit} \times 100}{\text{B.H.P. used in driving}}$$

A dynamo takes 80 B.H.P. to run it, and gives out 280 amperes at 200 volts to the lamp circuit. What is the commercial η?

$$\eta = \frac{280 \times 200 \times 100}{80 \times 746} = 93{\cdot}8 \text{ per cent.}$$

This means the ratio of the output to the input of the machine, and the larger the dynamo the greater it is, and it varies from 75 per cent. in the smaller sized dynamos up to 95 per cent. in the larger ones.

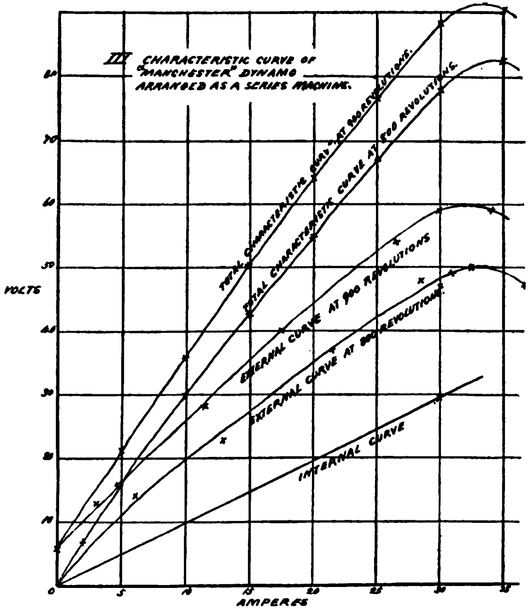

Fig. 95.

Characteristic Curves.—From the characteristic curves of a dynamo we can judge of its performance when at work, and also of its quality as a machine. Figs. 95 and 96 are from photos of curves, plotted out by us from actual tests taken on a dynamo, which was run successively as a series and a shunt machine. The external curve differs with the type of machine, that of a *series* being different from that of a *shunt* or *compound* machine.

The external characteristic curve of a *series dynamo* is got by measuring the amperes and volts at the dynamo terminals, and then plotting a curve from the readings. By multiplying together armature resistance and current, we can plot a curve for current and e.m.f. expended in the armature, which is a straight line. The horizontal lines or abscissæ represent the amperes flowing in circuit, and the vertical lines or ordinates the values of the voltage, and the intersection of these being points on the curve. Of course, the dynamo is run at a con-

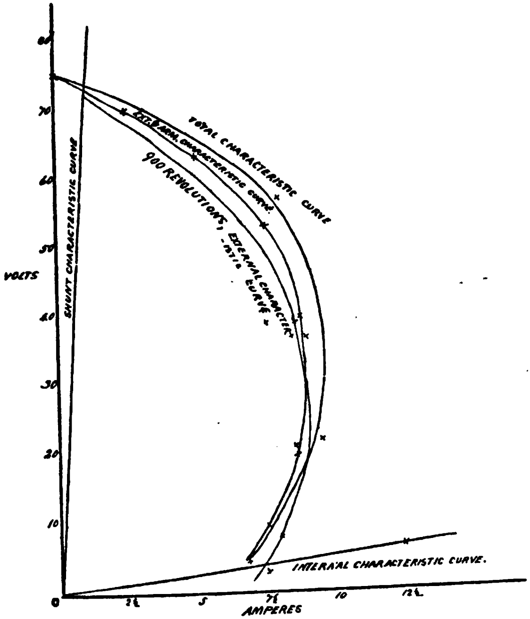

Fig. 96.

stant speed. The curve does not begin exactly at O, but a little way up the vertical; this is owing to a small e.m.f. existing, due to residual field magnetism. As current is generated the magnetisation increases rapidly; so does the e.m.f., and the curve rapidly rises, attaining a maximum height when the field magnets are saturated. If more current is taken from the machine the field magnets become demagnetised, and the e.m.f. at the terminals is decreased, as shown by the curve bending downwards.

By plotting the curve on squared paper (as shown in Fig. 95), it is possible to tell the output of the machine at any given instant. Suppose 18 amperes flow when 70 volts are developed, note down a point, call it A, which is the result of this experiment on the curve, other points are got also by running at different speeds, and the curve is formed by joining these points together.

A *shunt dynamo* has a different characteristic (Fig. 96). When the machine is disconnected from the circuit and the resistance is infinite, the D.P. at the terminals is a maximum (75 volts in this instance).

When a high resistance is put in the external circuit a feeble current flows, and the D.P. at the terminals falls slightly and does so as the resistance is reduced, and current increases. On further reducing the resistance, less and less current passes round the shunt coils, and they lose their magnetism. If this is continued, both the P.D. falls and current is lessened, and the curve turns backwards, and when the terminals are short-circuited the curve ends in a point, as both P.D. and current are at zero, and the magnetism is *nil.*

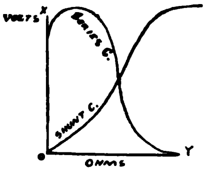

Fig. 97.

A *compound-wound dynamo* has again a different characteristic (Fig. 97). Here the ordinates represent volts, as before; but abscissæ give the ohms. There are two curves—one for the series and one for the shunt winding. The shunt curve shows the P.D. to be low at first, gradually rising as the shunt resistance increases; and it rises quickly when the external resistance is sufficiently high to allow of the field magnets becoming powerfully magnetised. The series curve is at its highest point when the external resistance is low and falls as the shunt curve rises, and from this fact it is possible to so proportion the series and shunt coils that the maximum effect of the one equals the maximum effect of the other, and thus the effect of the one diminishes as the other increases, and therefore the windings counterbalance each other, though the load in the external circuit varies, and we get a constant P.D. at the terminals, which makes the dynamo become self-regulating within certain limits for which it is designed. For further information, consult advanced text-books.

An Over-Compounded Dynamo.—In a central power station it may be required that a dynamo will give a constant electrical pressure at a feeding point some distance off. Then the dynamo has its series coils over-wound, or a greater number of turns of wire put on than are absolutely necessary, to raise the pressure at the terminals as the load increases, and compensate for the fall of pressure in the mains. From 10 per cent. to 20 per cent. of over-compounding is generally used.

Running Dynamos in Parallel.—When lamps are joined in parallel between the mains, a reduction in their number in circuit causes an increase of resistance and corresponding decrease in current strength, and *vice versâ;* and the D.P. between the mains must remain constant; it matters not what are the changes in the current strength, so it is often necessary, in a generating station, to put a dynamo into circuit with those which are running. A shunt machine, at rest, cannot be thrown on to the bus-bars to assist those that are running, because the bus-bars, being kept at a high voltage, such a heavy current would pass through the stationary armature (owing to the low resistance of this path) as would burn the coils and render the machine useless. Therefore, we must run up the dynamo to its normal speed to fully excite the field magnets and, when a voltmeter, between its terminals, registers the bus-bar pressure, then the machine is thrown into circuit and begins to assist the others.

In Fig. 98 there are two dynamos, D_1, D_2, supplying a common pair of mains; one brush, and one end of the field coils of both D_1 and D_2 are joined to the negative main by leads, in which are inserted switches, K_3, K_4, other switches, K_1, K_2, are placed between the other brushes of each machine and the + main. (A third switch may be inserted been the + main and the field-magnet coils.) In throwing out a machine from the circuit, we reduce the admission of steam to the engine cylinder till the current passing from the armature falls to a very small amount, when the armature switch may be opened without almost any sparking. In order to avoid further sparking on disconnecting the field coil, it should be shunted by a non-inductive resistance of about the same value, and, when the circuit is broken with the + main, the extra amount will circulate in this shunt and die away without almost any sparking at the switch contacts. A reverse current automatic cut-out is put in each dynamo-circuit, because, should the voltage of any machine fall low, currents from the others would pass through its armature and burn it; but with this apparatus the dynamo is cut out of circuit and is safe.

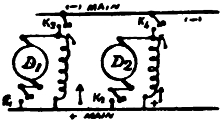

Fig. 98.

Series dynamos can be run together in series, but the current must be the same from each machine, though the resultant e.m.f. is the sum of the e.m.f. of each machine separately. The armatures of both are started running, and then, by means of a switch, both dynamos are joined in series with each other.

Compound dynamos will run satisfactorily together only when all their series coils are connected together by an equalising connection or "equaliser," which connects the ends of all the series coils direct to the ends of the + brushes of all the dynamos.

The Multipolar Dynamo (Fig. 99 shows a common type of machine).—As the demand for dynamos of greater and greater capacity arose, it was soon seen that the bipolar machine had a limit (about 250 kw.), and the next step was the multipolar machine, in which there are two or more magnetic circuits formed in the same armature core by arranging two or more pairs of field magnets around the periphery of the armature. A four-pole machine, with the same quantity of material as two bipolar machines, will have their combined output at half their speed. The magnet frame, of cast iron or steel, is a ring of large diameter, with brackets for resting on its foundation, and is divided into two half-rings with joints, where they are bolted together. On the inner periphery are fixed a number of steel pole-pieces, projecting radially towards the centre. These are provided with bobbins or spools, on which the magnet coils are wound. They are joined in series, and are wound to give alternately a positive and a negative pole at their free ends. The armature revolves between the pole-pieces, and it is wound with copper ribbon, coiled on a former, and insulated with a combination of paper, mica, and linen webbing; and this forms a spiral winding around the face of the armature, each turn being joined to a commutator bar. The windings join balancing-rings; each ring connects at equipotential points, thus ensuring a uniform e.m.f. between the parts of the machine. A set of carbon brushes are provided for each pole-piece. Recent machines are being built

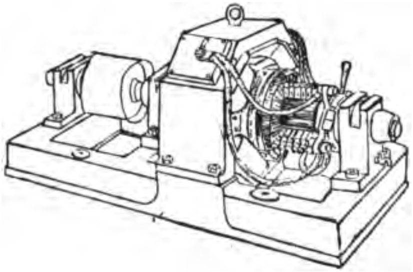

Fig. 99.

with an increasing number of poles, and generators of 1,000 kw. with 14 poles, and 1,600 kw. with 16, and 3,000 kw. with 24 are now running at 75 revolutions per minute for the larger, and 90 for the smaller machines.

Exercise.—A dynamo is situated 100 yards from the house to be lit. The conductor's resistance $= 0{\cdot}002\omega$ per yard, and there are fifty 50-watt 120-volt lamps in circuit. What is the voltage the dynamo must give?

The resistance of 200 yards (go and return conductor) of conductor at—

$$0{\cdot}002\omega \text{ (ohms) per yard} = (200 \times 0{\cdot}002) = 0{\cdot}4.$$

$$\text{Total watts} = 50 \times 50 = 2{,}500 \text{ watts}$$

and— $$\frac{\text{W}}{\text{E}} = \text{C} = \frac{2{,}500}{120} = 20{\cdot}8 \text{ amperes.}$$

Again— $$\text{E} = \text{C} \times \text{R} = 20{\cdot}8 \times 0{\cdot}4 = 8{\cdot}3 \text{ volts,}$$

which is the drop in voltage along the conductor. The lamps require 120 volts at their terminals, and, allowing 8·3 volts drop in the conductor, the dynamo must give $120 + 8{\cdot}3 = 128{\cdot}3$ volts—say 129—at its terminals.

A series-wound dynamo has an armature resistance of $0{\cdot}4\omega$ and a field resistance of $0{\cdot}6\omega$, and gives 120 volts at the terminals at a given speed, with a current of 10 amperes. What is its electrical efficiency?

$$\text{Output} = 10 \times 120 = 1{,}200 \text{ watts.}$$

Watts lost in the machine—

$$\text{C}^2 \times \text{R} = 10^2 \times ({\cdot}4 + {\cdot}6) = 100 \times 1 = 100 \text{ watts.}$$

Total power developed $= 1{,}200 + 100 = 1{,}300$ watts.
Total electrical efficiency

$$= \frac{1{,}200 \times 100}{1{,}300} = 92{\cdot}3 \text{ per cent.}$$

To make the above calculation the output must be known, and the resistance of the dynamo windings tested for beforehand.

Defects of Dynamos.—The principal defects or "diseases" of dynamos are:—

- (A) *Sparking* at the brushes.
- (B) *Heating*
  - At brushes, commutators, terminals, in armature, coils, or core, in the field magnets or pole-pieces, in the bearings.
- (C) *Speed*
  - Too high.
  - Too low.
- (D) *Failing to excite* or generate current.
- (E) *Short circuits*, set up in armature or field-magnet coils.

CHAPTER IX.

INDUCTION, STATIC TRANSFORMERS, CONVERTERS.

Induction.—(*a.*) *Self-Induction* or *Inductance* has already been referred to upon p. 68.

(*b.*) *Mutual induction* means the induction which a current produces upon neighbouring conductors. The quantity of magnetic induction, passing through one of two adjacent circuits, which is produced by unit current starting in the other one, is called the coefficient of mutual induction. In Fig. 100 PC = primary coil, through which a current flows from battery B. SC is a secondary coil, closed on itself, and connected with a sensitive galvanometer, G. When the two coils are fixed near each other, on closing the key K in PC, a momentary induced current passes round SC in the opposite direction, and causes the galvanometer needle to move. Whenever the battery circuit PC is opened, another current of short duration is set up in SC, which flows in the same direction as the current in PC. On making PC approach SC or SC approach PC, an instantaneous opposite current is set up in SC. In making either coil recede from the other, an instantaneous direct current is set up in SC. If the strength of current in PC is increased when both coils are at rest, an instantaneous opposite current is set up in SC. When diminishing the strength of current in PC, an instantaneous direct current is set up in SC.

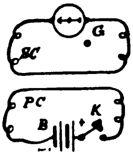

Fig. 100.

Suppose we insert an automatic make-and-break into the primary circuit PC, we would get a rapid succession of currents which would induce others in the secondary circuit SC, which would be stronger or weaker according to the resistance of the wire in the winding, and, in fact, this arrangement is what takes place in the *Induction coil*, where the windings are so arranged that the primary currents are of feeble e.m.f., and the secondary of high e.m.f., whereas in transformers the primary current is generally of high e.m.f., and the secondary of lower voltage.

In the above cases the induced currents are only set up in the secondary circuit, while the primary current is attaining its full strength from zero to maximum, or is on the decline. With a continuous current, when it has attained its full strength, the secondary current ceases; but with an alternating current in the primary circuit a secondary alternating current is being continually produced in the secondary circuit. The reason being, that whenever a current flows along a conductor, it produces a magnetic field around the conductor (see p. 15), the diameter of which depends on the current strength. Should this field happen to fall on any closed circuit and get cut by it, it produces in this closed circuit a feebler magnetic field, but otherwise of the same nature. If the "positive direction" of the primary field (see p. 15) is clockwise, then the lines of force, being reflected by the secondary circuit, have their "positive" direction changed into anti-clockwise, and these directions show currents flowing one way in the primary, and the opposite way in the secondary circuit. Now, it is only at the moment when the original magnetic field is cutting the secondary circuit that the secondary magnetic field is generated. On opening the circuit the primary field collapses, passes inwards and disappears in the primary circuit, and, in doing so, it again cuts the secondary circuit and sets up an instantaneous secondary current; but as the conductor is now cut from the opposite side the current flows in the same direction as in the primary.

Transformers are of two kinds—first, for alternating current, and second, for direct current.

(*a.*) *An alternating current* or *static transformer* (Fig. 101) consists of two coils wound upon a laminated iron core, which forms a closed magnetic circuit of low resistance. There is a fine wire and a thick wire coil placed side by side. The coils are separately wound on bobbins and placed around the core, one within the other, as in a shell T., or the primary may be wound in two halves, joined up in series or parallel, with the secondary inserted between them, as in a core T., or, again, the secondary may be in two sections and the primary put between them, as in the Berry T., or wound one over the other. The coils are well insulated from each other with mica or other good insulator. A current is supplied to one coil, and current in the other coil is generated by induction, caused by the continual reversals of the current. If the number of convolutions in both coils are the same, then by sending a current through the primary coil an alternating current of the same voltage is got in the secondary coil. Or the secondary might consist of many turns of fine wire and the primary of a few turns of thick wire; then as the primary lines of force would cut the secondary circuit very often, the induced e.m.f. would be higher than the primary and the current smaller: this forms a "*step-up*" transformer. Again, if we use a fine-wire coil on the primary of many turns and a thick coil on the secondary of few turns, as the primary resistance is high, it requires a high e.m.f. to send current through it; but the secondary current, induced, is heavy and the e.m.f. low. This forms a "*step-down*" transformer, which is the more common form. The secondary e.m.f. always bears the same ratio to the primary e.m.f. that the number of convolutions in one coil bears to those in the other. Thus the induced voltage depends on the number of magnetic lines of force generated by the primary current and the number of turns of wire in the secondary coil which they cut. Let the primary coil PC in Fig. 101 consist of 1,000 turns of fine wire, and the secondary of 10 turns of thick wire, SC, and a current of 1 ampere pass through PC at 500 volts, then the secondary current might be 100 amperes, and the induced e.m.f. = 5 volts; for 1 × 500 = 500 watts and 100 × 5 = 500 watts.

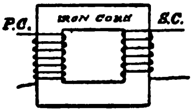

Fig. 101.

Here, theoretically considered, the output equals the power put in; but in actual practice this is not the case, although the output may be as high as 95 per cent. Thus we see that static transformers are very convenient; being automatic in action, and having no moving parts, they require little attention, and they do not readily go wrong or break down. We speak of the ratio of transformation being 10, 20, or 30 to 1 in a step-down transformer, which means the secondary e.m.f. induced is $\frac{1}{10}$, $\frac{1}{20}$, or $\frac{1}{30}$ of the primary e.m.f. Again, a 10, 20, 30 to 1 step-up transformer is one where the secondary e.m.f. is 10, 20, or 30 times as great as that in the primary e.m.f. On open circuit the ratio between the e.m.f.'s in the two windings is proportional to the ratio between the number of turns. Thus, if the secondary have $\frac{1}{20}$ of the number of turns that the primary has, its e.m.f. will be $\frac{1}{20}$ that of the primary. There are different types of transformers, but all contain laminated iron cores and a closed magnetic circuit. Plenty of air must have access to the windings to keep them cool. Sometimes they are oil-insulated and water-cooled. A short time ago transformers of 40 or 50 kw. at 5,000 or 10,000 volts were the limit, but now they are made for 2,000 or 3,000 kw. at 50,000 to 60,000 volts. The losses in a transformer are due to heating of the coils—viz., the C^2R losses, heating of the iron cores by eddy currents, and hysteresis; there is also leakage from these causes.

In electrical transmission of energy the voltage is raised at the power-house by step-up transformers to, say, 5,000 volts or over, and a small current is sent along the line (see p. 179) to the point of distribution, where step-down transformers supply a large current at, say, 500 volts for power purposes, and 200 volts for lighting purposes. The advantage consists in this: that it is expensive, from the weight of copper used, to convey a heavy current, as 250 amperes or more, for a distance of many miles, whereas 1 ampere, at a high voltage, can be transmitted by a small conductor for many miles very cheaply, as such a small amount of copper is required in the conductor. Thus transformers are greatly used for distributing currents over large areas in varying quantities at different voltages, being joined on the primary side to small thin conductors of a given capacity, and placed near to where the current will be used. A 90-kw. transformer costs about 28s. per kw., and three 30-kw. transformers put in its place, it is said, would cost 46s. per kw. Thus the cost is increased as the output is diminished. The efficiency of the three-phase is less than that of the single-phase transformer.

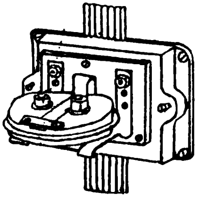

Fig. 102.

From any cause should a connection get accidentally established electrically between the primary and secondary windings of a transformer, the voltage would rise dangerously high in the secondary circuit, burn the coils, break the lamps, and perhaps shock or kill some of the attendants. The Board of Trade require that some precaution should be taken to prevent the secondary winding rising to a high potential, if the insulation between the primary and secondary coils of the transformer break down. The Cardew earthing device (Figs. 102, 103) is widely adopted for this use. There are two horizontal circular plates, the upper one, S, connected to the wiring on the consumer's premises, and the other, S^1, goes to earth, E; a piece of aluminium foil, T, rests on the lower one. If the potential from earth exceeds a certain amount, the electro-static attraction of the plate on the tinfoil raises one end of it and connects the two plates together, thus blowing the main fuse, should the increase in potential result by leakage from the primary winding. The apparatus is inclosed in a cast-iron box with removable cover, and the two insulated discs are held in place by three springs: they can easily be removed and replaced. Transformers are placed in substations, or in brick buildings, under the roadways, these last being entered

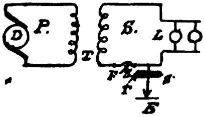

Fig. 103.

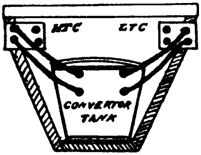

Fig. 104.

by a manhole in the roof (Fig. 104), where HTC are the high-pressure mains and LTC are the low-pressure mains, which join with the transformer windings inside the case. Some makers have introduced a combination of a lamp column with an overground transformer box, each of which carries a 50-kw. transformer. This transformer box is produced at a lower cost than an ordinary substation.

We wish to transmit 834 kw. alternating current, and then transform it into continuous current for lighting or power purposes. What output must the generator give to allow for losses in conversion, transmission, &c.? Say the efficiency of the converter = 90 per cent., that of the static transformer = 93 per cent., and that of the three-phase transmission = 90 per cent. Suppose the generator gives 1,390 amperes at 600 volts,

$$1{,}390 \times 600 = \frac{834{,}000}{1{,}000} = 834 \text{ kw.}$$

This would do if there were no losses, but as there are, the output from the generator must be—

$$\frac{1{,}390 \times 600}{1{,}000 \times \cdot 9 \times \cdot 93 \times \cdot 9} = 1{,}107 \text{ kw.}$$

The ratio of conversion is 20 to 1 on 1,000-volt apparatus and 40 to 1 on 2,000-volt apparatus when using 52 volts on the secondary of the transformer. The efficiency of conversion is from 95 per cent. to 97 per cent.

Find the total current required on a 1,000-volt primary circuit having 600 16-c.p. lamps on the secondary. Current required on the secondary for one 16-c.p. 52-volt lamp is 1·04 ampere. Current required on the primary circuit for one 16-c.p. 52-volt lamp is got by dividing the total amount of current on the secondary circuits by the product of the ratio and efficiency of conversion—

$$\frac{\text{current}}{\text{ratio of conversion} \times \text{efficiency of conversion}} = \frac{1 \cdot 04}{20 \times \cdot 95} = 0 \cdot 0547 \text{ ampere.}$$

Therefore current required on the primary circuit for 600 16-c.p. 52-volt lamps is 0·0547 × 600 = 32·82 amperes.

(*b.*) *A continuous-current transformer* or *converter* is a machine which converts alternating into continuous current, or *vice versâ ;* it has moving parts and so requires a skilled attendant to look after it. The machine consists of a combination of a motor and a dynamo, or a motor and an alternator. Such a conversion of energy could be effected by making the primary current run an alternating current motor, and this in turn drive a continuous-current dynamo, or, by reversing the process and making the continuous-current motor drive an alternator, and so give out alternating current. The double-current generator consists of a dynamo and an alternator combined in one, which transforms electrical energy, supplied to it in one form, into an output of energy in another form. For instance, one machine converts continuous current at one voltage into either single, two, or three-phase alternating currents at a different voltage. Another, again, changes alternating currents of different phases into continuous currents.

There are two forms of this machine:—(*a*) The direct-current transformer, or motor dynamo, is used to lower or raise the pressure of a continuous current. It consists of a motor and generator directly coupled together, the two armatures revolving in separate fields. Sometimes the windings are fixed on the same core, and revolve in a common field, there being a separate commutator for each winding. At Cowes, Isle of Wight, there are two Parker two-pole motor transformers; total kw. 105. These are supplied by high-tension continuous current generated at Newport (some miles distant) at 2,500 volts, and give out continuous current, at 480 volts, for the three-wire system supplying E. and W. Cowes. (*b*) The converter proper (Fig. 105) consists of an armature A, having a commutator C on one side with brushes B^1, B_2, and on the other two slip-rings R, R', on which brushes B_3 B_4 rub. A revolves in a bipolar field, and has only one winding. This machine will give off both alternating and continu-

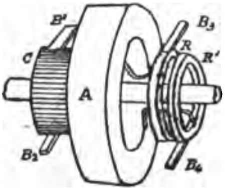

Fig. 105.

ous currents. Again, should the machine be supplied or driven by an alternating current, it will generate continuous currents on the commutator side, or, if run by continuous current, it will generate single-phase alternating currents on the slip-ring side (or it might be made to generate polyphase currents instead). A machine of this kind is mostly used to transform polyphase currents to continuous currents. On three-wire systems motor dynamos, with equal windings, are used to balance the two sides of the system, and they are called *balancers* or *equalisers*. There may be four dynamos all running on the same shaft. The term "booster" is applied to certain forms of motor dynamos, which are used, for instance, for transforming up, or boosting up, the voltage of the driving current. Thus we have battery-charging boosters, feeder boosters, and balancing boosters, &c. For a description of these the student must consult an advanced text-book, such as "Electric Lighting and Power Distribution," by Maycock.

CHAPTER X.

MOTORS.

Electric Motors (1st Continuous Current Type).—These machines convert electric energy supplied to them into energy in the form of mechanical motion, and this action may be explained as follows:—If we put a current-carrying conductor, such as a wire loop, into a powerful magnetic field, passing between the poles of an electro-magnet, the field of the latter will be at right angles to that of the former, and a force or *Torque* is set up tending to drag the conductor across the field, which is proportional to the product of the strengths of the two fields. The lines of force of the two fields will tend to alter their shape, so as to coincide in direction, and run side by side; they also tend to shorten and repel each other. So, if the wire loop be placed with its edges towards the pole-pieces (Fig. 106), the lines of its field will project at right angles to those of the fixed field, and the loop, if free to move, will turn round through 90° (see dotted lines, Fig. 106), when the lines of the field magnet thread through it in the same direction as its own lines, and it rests there when the lines which pass through it are a maximum. If the current, passing through the loop, be reversed in direction, it will turn completely round till the lines of both fields again coincide. Thus we can impart mechanical motion to a wire loop or armature, and a continuous rotary motion can be kept up by reversing the current in the armature just when the momentum has carried it slightly beyond the position of

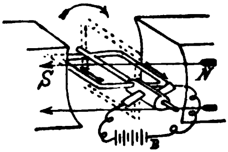

Fig. 106.

rest. Current in motors is supplied by brushes pressing on the commutator segments, and so placed that each segment and armature coil slides into contact with a fresh brush, just as it arrives at its position of rest. By this means current is reversed, and a continuous rotation kept up. With two coils the armature might suddenly stop on a dead point, and would not start again of itself. With many coils there are no dead points in the machine, because when certain coils are on the dead-centres others are receiving current at maximum potential, and so a continual rotation is kept up. Just when a coil arrives at the dead point, current is reversed, causing it to exert a similar force in the opposite direction during the next half-revolution. Motor armatures are, like those of dynamos, of the ring, drum, or flat disc type, and every one must be able to resist sudden heavy stresses without risk of damage, such as the effort to start with a heavy load. Motors are either two-pole, three-pole, or multipolar; and from their winding are either series, shunt, or compound-wound. *Series-wound motors* are used where great starting power is required, as for cranes, pumps, hauling-gears in collieries, and traction purposes; but they do not give a constant speed with a variable load, but shunt-wound motors do, within the limits of which they are capable, though they have less starting power.

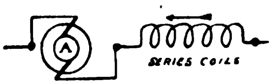

Fig. 107.

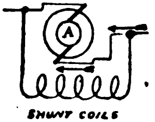

Fig. 108.

A series machine (Fig. 107) as a motor turns in an opposite direction to what it would do running as a dynamo, if the connections in both cases are the same.

A shunt machine (Fig. 108) runs as a motor in the same direction as it would do if run as a dynamo. In these, when the e.m.f. is steady, the excitation of the field magnets is always the same; the current in the armature only changes, and they run at a uniform speed with varying loads, so if the load be increased the speed and the counter-e.m.f. fall; a stronger current then passes through the armature, and exerts a stronger torque, and speeds up the machine.

A compound-wound motor (Fig. 109) runs in the same direction as it would do if used as a dynamo, the polarity and field magnets remaining the same.

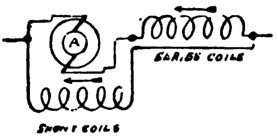

Fig. 109.

Suppose the radius of the armature = 8 inches, and a pull of 40 lbs. is applied at a point on its circumference, at right angles to the radius, then the torque = 40 × 0·66 = 26 foot-pounds. In an armature the pull is exerted at a number of equidistant points, or at every armature conductor. Suppose the number of active conductors round the circumference = 150, and the pull on each = 20 lbs., and diameter of armature = 18 inches (radius = 9 inches = ·75 foot), then torque = 150 × 20 × ·75 = 2,250 foot-pounds (Fig. 110).

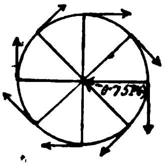

Fig. 110.

When a motor is being driven by a current, the revolutions of the armature in its field develop an e.m.f., which is counter to, or opposes the impressed e.m.f., and so acts like a resistance to reduce the amount of current flowing into the machine. This is called the "counter-e.m.f." The higher the speed the greater is the counter-e.m.f., and consequently the feebler is the strength of current going to drive the motor. When the armature is at rest, as its resistance is low, a heavy current would pass through it on starting, if allowed to do so. As the armature revolves, current falls till the speed and the counter-e.m.f. get so high that only a small current can flow into it with a reduced torque. This variation is convenient. When a motor starts with a load on, it must exert much more power than when running: then a large current can pass through the armature and exert great power on the shaft, while the current falls to a safe value before any damage is done by overheating, owing to the counter-e.m.f. keeping back the driving current; for if the load was suddenly thrown off, the speed attained would cause the counter-e.m.f. to reach so high a value that very little current would pass through the armature, and little electrical power would be expended. Thus the counter-e.m.f. automatically regulates the demand for power, and acts like the governor of a steam engine.

The commercial efficiency of a motor is the ratio of mechanical power given out to the electrical power put in—

$$\text{Percentage commercial efficiency or } \eta = \frac{\text{mechanical power given out} \times 100}{\text{electrical power put in}}.$$

The electrical efficiency is the ratio of the electrical power used to that supplied to the machine—

$$\text{Percentage electrical efficiency or } \eta = \frac{\text{electrical power turned into motive power} \times 100}{\text{electrical power put in}}.$$

$$\text{Mechanical } \eta = \frac{\text{mechanical power given out for useful work}}{\text{electrical power converted into mechanical power}}.$$

When a motor is at rest, if the full amount of current was suddenly switched on, it would all pass through the armature and damage it by burning the coils, and this must be prevented.

Starting Switch for a Series-Wound Motor (Fig. 111).—When the starting switch, sw, is on the outer contact 1, no current can flow through the motor. When the switch is put on contact 2, current passes through the whole of the resistance to the armature. As the motor speeds up, the switch is gradually moved over the stops to the last contact, when the full pressure is applied. By varying the terminal pressure with a variable resistance the speed can be altered; but it is always proportional to the pressure and the torque applied. These motors are used for driving pumps, fans, &c., where there is a constant load and a good starting torque is required.

Starting Switch for a Shunt-Wound Motor (Fig. 112).—Current passes first through the field coils FM, then through the armature A, having a resistance in series which is cut out afterwards. One end of the armature and FM circuits are joined to T (–); the other ends, as well as the resistances R_1, R_2, R_3, join contacts 1, 2, 3, 4, 5, 6. A contact-arm, CA, is rotated by a handle. When CA is moved to connect 1 and 2, current passes through the FM coils. Further movement joins 1, 2, and 3, and sends current through the resistances R_1, R_2, R_3, to the armature. The last movement of C short-circuits the resistance and cuts it out. This machine runs faster if the field excitation be weakened, and slower if it be strengthened, the load being constant.

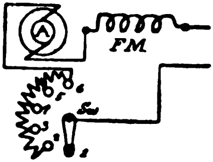

Fig. 111.

The rule in starting and stopping motors is to switch on the current first and move the rheostat switch last. In stopping, we always open the starting switch first and then the rheostat, to put in all the resistance in series with the armature to prevent an inrush of current when the motor is started again.

When a number of motors are run off mains, an apparatus is used to disconnect each, in the event of an abnormal increase of current taking place, or a fall of voltage across the terminals. This is called an automatic release starter, when combined with the ordinary starter. There is also an excess current, or overload, release used. Sometimes self-starting rheostats are used which are operated by electrical control from a distance; but, for a description of all these, the student must consult advanced text-books.

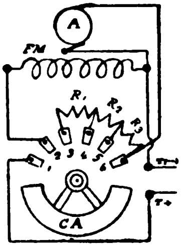

Fig. 112.

Motor Reversing Gear.—The current always passes in the same direction through the field coils (Fig. 113), but its direction through the armature is altered according to whether the switch, *sw*, is on contact 1 or 2. When on contact 1, current will pass upwards through the armature A, causing it to run in one direction, and when *sw* is put on contact 2, current will pass downwards through the armature, and the machine will run in the opposite direction. For every horse-power delivered at the motor-shaft we must supply 1·2 H.P. at the generator terminals. To find the current required by a motor when the H.P., the efficiency, and the voltage are known, let C = current, H.P. = motor's H.P., E = motor voltage, η = efficiency (we take this at from 75 per cent. to 90 per cent.). Then—

$$C = \frac{\text{H.P.} \times 746 \times 100}{E \times \eta}.$$

Motors are divided into two types:—First, the *open* type; second, the *enclosed* type. The *first* is used in dry places, where much dirt and dust are not likely to occur.

The *second* is used in places where it is subjected to rough usage and to the influence of wet and dirt. Fire Insurance Companies prefer this type. The armature, field coils, and commutator are protected by the framework.

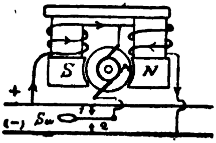

Fig. 113.

Motors are used in shipbuilding yards, dyeing, bleaching, calico-printing, paperworks, sugar refineries, iron and steel works, for driving and bending rolls, punching machines, drills, cranes, hoists, elevators, turntables, fans, pumps, locomotives, tramway cars, motor cars, electric launches, &c.

Alternating-current motors are of two kinds, Synchronous and Asynchronous motors.

(*a.*) *The Synchronous Motor.*—If a single-phase alternator has its current sent through another alternator, which has been run up to the same speed as the former, the latter will run as an alternating-current motor. In both machines the field magnets must be excited with direct current, and both must correspond in frequency; but if the motor be overloaded it is apt to stop. If two polyphase alternators be joined together in the same way, one being the generator, the other will run as a motor, if current from the former passes round the field coils of the latter, and the motor will run in synchronism or at a speed corresponding to that of the generator.

This form of motor is not used where a large starting torque, or frequent starting on the load, is necessary, and it does not admit of independent speed regulation.

(*b.*) *The Asynchronous*, *non-synchronous*, and *induction-motor* is one the speed of which is independent of the frequency of the driving current, whether that is monophase or polyphase. The moving part or armature in this machine is called the rotor, and has no slip-rings or commutator, currents being induced in it which cause its rotation. This part corresponds to the secondary coil of a transformer in which secondary currents are induced. The fixed part of the machine is called the stator, into which the high-pressure currents pass, and these set up a rotating magnetic field which the rotor follows. The stator corresponds to the primary coil of a transformer. The Arago disc illustrates very well the meaning of a revolving field (see Fig. 114). A copper disc, CD, on a vertical axis is rapidly rotated by a hand wheel, HW, by means of a belt. Close over CD is put a compass needle, NS. On rotating the disc either way, the needle is deflected, and if the speed be great enough, and the deflections exceed 90°, the needle rapidly rotates. The magnetic field set up by the compass needle passes partly through CD. In rotating, CD cuts these lines of force, and produces eddy currents in itself. Near the poles these currents are at right angles to the lines of the field and direction of motion and flow parallel to the needle, and so it is deflected, and if this exceeds 90° it is set in rotation. We might rotate the magnet, and then the disc would be set in rotation by the mechanical couple produced. Here the magnet is the field to be rotated by power, and the disc equals the

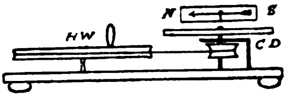

Fig. 114.

motor armature. To make a machine on this principle, and get commercial success, we must produce a rotating field without actually rotating a physical magnet, and this was done by Ferraris and Tesla. Ferraris used a two-phase current; his machine, constructed in 1885 (Fig. 115), consisted of two pairs of electro-magnets, MM′, NN′, joined by yoke of iron wire Y. Within the polar cavity was placed a copper cylinder or armature, A. Two currents were used to energise the magnets. Let C_1, C_2 be the two currents energising MM′, NN′. C_1 is at zero when C_2 is maximum with a phase difference of 90°. When C_2 is maximum then C_1 is zero, and *vice versâ*. Thus at one moment the field is horizontal, then vertical, then horizontal again, and so on, the resultant field corresponding to the frequency of the supply currents. This illustrates the two-phase system with the two e.m.f.'s and currents at 90°, or one-fourth of a cycle, apart, and the relations of the currents to each other are such that the maximum of one occurs when the value of the other is zero. With a two-phase system either four or three-line wires may be used. By joining any two of the four conductors, a common return is made for the two circuits. This arrangement is called the two-phase three-wire system.

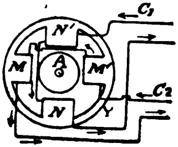

Fig. 115.

The three-phase (there is no advantage in using more phases) system is much used for transmitting energy. In this the three e.m.f.'s and currents are 120° apart, and the impulses follow each other at 60°.

The modern *polyphase motor* consists of one part, called the *stator*, into which the polyphase currents pass, and the other part called the *rotor*, in which the currents are induced which cause its rotation. There is no electrical connection between the stator and the rotor. The first corresponds to the primary coil of a transformer, through which the high-pressure currents pass, and the rotor corresponds to the secondary coil of the transformer, in which the secondary currents are induced. One of these motors is easily started by throwing it into the full voltage of the circuit, and this does no damage, or produces sparking, but gives a heavy starting torque.

The windings of three-phase generators are usually joined up as "*Star*" or "*Mesh.*" In the first, the armature coils are joined to a common junction from which they branch starwise, each to its own line. In the second, the coils are connected in series, and the line wires join points between the coils, forming thus a closed triangle without any common centre. When the motor is running light, the speed of the rotor is about that of the rotating field produced in the stator, or nearly synchronous. When running under load the speed of the rotor falls slightly, and the difference of this speed and that of the revolving field is called the "slip," and is proportional to the resistance of the rotor.

There are no collecting rings, brushes, or sliding contacts, and so there is no chance of a spark except at the starting switch, which can be put at a distance off. Therefore this motor is suitable for running in fiery coal-mines and factories where there is inflammable material about. These machines are being now much used in America and this country for factory driving, cranes, and printing machinery, &c. Some electrical railways are run by means of these motors.

Many firms in America, on the Continent, and in Great Britain, drive their machinery by means of three-phase motors, so that multiphase working is now becoming very general. Lately the single-phase motor has been adopted for railway work in America by the General Electric and Westinghouse Companies.

CHAPTER XI.

PRIMARY AND STORAGE CELLS.

I. **Primary Cells.**—A primary cell produces current by chemical action going on in its interior. It becomes active whenever the positive + plate is joined to the negative (–) plate, and when its energy is exhausted it requires a fresh supply of material to render it active again. On p. 2 we gave a very simple form of cell in which only one solution is used (it being of the single-fluid variety). The plates are of copper and zinc, and whenever the + plate and the (–) plate are joined together by a conductor, a flow of current takes place.

Different forms of cells are used, such as *Leclanché*, *Bichromate*, *Daniell*, *Dry cell*, &c.

The Daniell cell belongs to the double liquid variety. It consists of an outer porcelain vessel containing zinc. Inside is placed an unglazed earthenware vessel containing a thin sheet of copper. The porous vessel is filled with a saturated solution of copper sulphate (which contains some fragments of undissolved sulphate in the solution); the outer vessel contains one part of sulphuric acid or zinc sulphate, with from 12 to 20 parts of water. This is a standard cell used for testing purposes, and gives an e.m.f. of 1·07 volt when properly made.

Leclanché Cell.—In this a zinc rod forms the + plate, and a carbon rod the (–) plate, or prepared carbon is placed in a porous earthenware vessel filled with a mixture of powdered carbon and black oxide of manganese. The solution is chloride of ammonium or sal ammoniac. The e.m.f. = 1·5 volt. This cell is much used for electric bells.

Bichromate Cell.—This contains a solution of bichromate of potash in a glass vessel, in which are placed carbon and zinc plates (there is always one more carbon than zinc plates). All the carbons are joined together; so are the zinc plates. The latter can be easily removed out of the liquid by a small rod, and withdrawn to save wasteful consumption of zinc. The e.m.f. = 2 volts.

The "Obach" Dry Cell.—The containing cylinder is composed of zinc, which forms the + plate, a carbon rod forms the (–) plate. Inside the zinc cylinder is a lining of plaster of Paris, flour, chloride of zinc, and sal ammoniac forming a paste. Surrounding the carbon rod is also a paste composed of carbon, peroxide of manganese, chloride of zinc, and water. The top of the cell is coated with a layer of pitch resting on a layer of silicated cotton; a small hole at the top allows the gases to escape; the e.m.f. = 1·5 volt. For further particulars about primary cells, the student must consult a text-book * on "Electricity and Magnetism." Cells are joined up in *series* and *parallel* arrangements. In *series* the cells are joined up in tandem fashion, or one behind the other (Fig. 116). The + pole of one cell joins the (–) pole of the next one, and so on, and when all are joined up there will be two unconnected poles left—viz., the + pole of the first one, and the (–) pole of the last cell in the series (the long lines representing the + poles and the short lines the (–) poles). The number put in series depends on the e.m.f. required. If a greater rate of discharge is required, two or more cells must be joined up in *multiple series*, or *parallel* (see Fig. 117).

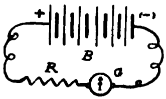

Fig. 116.

Exercise.—What current will a battery of six Daniell cells, in series, give, and at what voltage? The e.m.f. of each cell = 1 volt. Internal resistance R of each = 4 ω. External resistance $r = 4$ ω. Then—

$$C = \frac{E}{R + r} = \frac{1 \times 6}{(4 \times 6) + 4} = \frac{6}{28} = 0{\cdot}214 \text{ ampere.}$$

In this arrangement the total e.m.f. of the battery equals the sum of the e.m.f. forces of the various cells. In parallel (Fig. 117), cells are joined up for quantity, or they give a larger current at a smaller voltage. By this arrangement the internal resistance is diminished, but the total e.m.f. of the battery is only that of the number of cells in series in each set. Suppose we put six Daniell cells in parallel, what is the current and voltage? We gave what this is with them joined in series. First find the internal resistance of all the cells in parallel by the formula (see Munro and Jamieson's "Pocket-Book") "$\frac{ns \times \text{R}}{nq}$, where ns = the number of cells in series in each set, R = the internal resistance of each cell, and nq = the number of sets in parallel." Then—

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* Such as Jamieson's "Elementary Manual of Magnetism and Electricity."

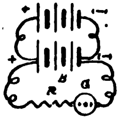

Fig. 117.

$$\frac{ns \times \text{R}}{nq} = \frac{3 \times 4}{2} = 6\omega.$$

Again—

$$\text{C} = \frac{\text{E}}{\text{R} + r} = \frac{1 \times 3}{6 + 4} = \frac{3}{10} = 0{\cdot}3 \text{ ampere.}$$

So the current is greater, but the voltage less, than before. The internal resistance of a cell varies inversely with the size of plates and the distance between them. So, if we double the size of plates, we halve the resistance and increase the current strength. This is also got by joining the cells in parallel: then current increases, but the voltage falls. The arrangement to give the strongest current strength with any number of cells is when the internal resistance equals the external resistance. The grouping of a number of cells together is called a battery. This may be a primary, or a secondary one, according as the cells are primary or secondary which compose it.

II. **Storage Cells.**—There are many different types of cells in the market—such as the *Tudor*, the *Chloride*, the *Lithanode*, the *E.P.S. cells;* but for a detailed description of these the student should consult an advanced text-book.

A *secondary battery* or *storage cell* requires current to be sent through it from a continuous-current machine to render it active, and then it will, after being charged, supply current when the + plate is joined to the (–) plate till the discharge is exhausted, when it must be recharged as before by a current, and this process of charge and discharge can be often repeated during the life of the cell. Storage cells were made possible in 1860 by Plante's discovery of the spongy lead and peroxide of lead formed out of sheets of metallic lead by an electric current. He took two plates of lead and suspended them in dilute sulphuric acid (1 to 10 parts of water); the cell was charged till gas was given off, showing that the plates were peroxidised. The cell then was discharged and charged in the opposite way to the previous charge; this alternate charging and discharging being repeated many times before the cell was "formed," *i.e.*, the + plate peroxidised and the (–) plate reduced to spongy lead. It was only then that the cell acquired any amount of capacity or capability of holding a charge. A potential difference of 2 volts was found to be set up between the plates when fully charged. It was only in 1880, by Faure's invention of pasted plates, that the storage of electricity and the accumulator industry became commercially possible. He mechanically applied to the plates a paste made of red lead (Pb_3O_4) and sulphuric acid. This formed lead sulphate. In charging the cell the paste on the + plate was reduced to PbO_2, and that on the (–) plate to spongy lead, thus accelerating the formation of the plates.

This battery of Faure's produced a sensation at the time, and Lord Kelvin (then Sir William Thomson) wrote in 1881 to the *Times* as follows: "The marvellous box of electricity received from Paris has been tested and measured in my laboratory in Glasgow, and the results point to its great practical value. The problem of converting energy into a storable form, and of laying it up in store conveniently for allowing it to be used at any time when wanted, is one of the most interesting and important in the whole range of science. . . . The million foot-pounds, kept in a box during 72 hours' journey from Paris to Glasgow, was no exaggeration. One of the four cells after discharge was recharged and left alone for ten days. It then yielded 260,000 foot-pounds."

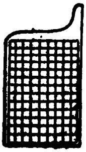

Fig. 118.

The modern type of Faure cell has the lead plates cast in the form of grids (Fig. 118), *i.e.*, with perforations in which the paste is packed. The (–) plates are in the form of grids, but the + plates are solid in the centre, and have ridges on each side; the former have a paste of litharge packed into them (PbO and sulphuric acid), the latter red-lead and acid.

The + plates are of a light brown colour (in uncharged condition), and are always one less in number than the (–) plates (Fig. 119). The + and (–) plates are fixed alternately; the two outer are always (–) plates, and there is a negative facing on each side of every + plate. The (–) plates may be seven or more in number of a greyish colour. They are all joined together, and so are the positives. Lead grids are provided, with massive lugs, for joining them together. The lugs of the + plates are all melted or cast on to one leaden strip, so are the lugs of the (–) plates. Ebonite forks, or separating rings, are placed between the plates to keep them apart fully ¼ inch, and prevent internal contact. Inside the cell the plates should rest upon paraffined or varnished strips of wood about 1½ inch above the bottom of cell. The vessel may be of lead; but glass is better, as the interior can be inspected. The outer and upper part of the vessel should be coated with paraffin-wax, vaseline, &c., to prevent "creeping" or loss of current and partial short-circuiting, from the continuous film of moisture which condenses on the whole outer surface. Cells should sit on varnished wooden trays containing sawdust, and be fixed on insulators. Lineham gives "4 parts acid to 21 parts of distilled water (both by measure.)" The electrolyte (1 of acid to 5 of water) is composed of dilute sulphuric acid, sp. gr. 1,190. This can be purchased ready for pouring into cells, diluted and made up from 1·15 to 1·2. Cover the plates completely to within a short distance of the top of the cell. Never pour the acid

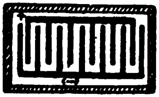

Fig. 119.

into the cells after they are fixed up till all is ready to begin charging.

Sometimes caustic soda is added to the acid in the strength of 1 oz. to 1 gal. water: 1 oz. of this is added to 5 oz. of water before pouring into the cells. This is said to preserve the cells, especially if they are left long standing idle, but the practice is not to be recommended. After the acid is poured in, the top of the cell is covered over with a plate of glass to prevent evaporation, and this causes the spray to fall back when charging. The plates must be kept always covered with liquid by adding water as required to make up for loss by evaporation. Each cell of whatever kind gives an e.m.f. of from 2·4 to 2·5 volts. As generally from 50 to 60 to 80 to 100 volts are required for lighting, we require from 25 to 30 cells, or rather 27 to 54, in order to have a few in reserve.

To determine the number of cells required to form a battery in any installation, we use the rule given in Munro and Jamieson's "Electrical Pocket-Book":—"Divide the e.m.f. or voltage of the lamps by two, and add two cells to the total thus found for a 50 or 60-volt installation, but add three cells instead of two in the case of a 100-volt installation." Cells are arranged in tiers on strong wooden shelves, protected by shellac varnish, and should be so placed that the edges of the plates are in view. Allow a space of 22 inches at least between the shelves; about ½ inch space must be allowed between each tray. All the junctions of the cells must be made in thorough electrical contact by scraping, and have all nuts firmly tightened up, or they will offer much resistance and get hot when current flows. The cells should always be kept in a dark place, as sunlight causes evaporation and spoils them. Always attach the + terminal of the battery to the + terminal of the dynamo, and the (–) terminal of the battery to the (–) terminal of the dynamo; all the cells being joined up in series, the positive of the one to the (–) of the next, and so on. The + cells are painted red at the terminals to distinguish them. It is a good plan, before joining the cells up to the dynamo, if we are uncertain, to test for the polarity of the dynamo. This is done in different ways:—(1) By means of a pole tester, which is a glass tube containing iodine compound in glycerine. One knob is joined up to the + terminal, the other to the (–) terminal. This last changes to a purple colour, but returns in time to its original colour (Fig. 120). (2) Use pole-finding paper; a prepared paper is sold for this purpose. When it is damped and allowed to touch the wires from the two dynamo terminals, that end connected with the negative terminal turns red. (3) Use two lead strips put in a vessel containing dilute sulphuric acid, each being connected to the + and (–) brushes. When a current flows, that connected with the + brush becomes dark in colour.

Charging for first time.—Always start charging with an ammeter and voltmeter in circuit. Begin with a small current, about one-third of the normal output for four hours, then increase to the normal current for about twenty consecutive hours, until the + plates get a dark brown colour, of peroxide of lead, or till the cells boil or get milky, or till all the globules rise to the top in a Hicks' hydrometer, which is inserted into each cell in succession, or till the sp. gr. rises to 1,195 or 1,210, as shown by a sp. gr. glass inserted in each cell, or till a small voltmeter, attached between the + and (—) plates of any cell, gives a voltage of 2 to 6 volts per cell. If possible, do not stop charging at the end of that time, but continue at a lower rate, gradually reducing the charging current to one-fourth of the normal rate, at which continue till the above voltage is obtained. Always charge through an automatic switch and alarm bell. The former, in the event of the dynamo voltage failing, cuts out the machine, for if there is a breakdown and the dynamo fails to run as a motor, such a strong current would pass through the armature (of low resistance) as would burn it. The automatic alarm bell indicates when an excessively high current is being drawn from the cells.

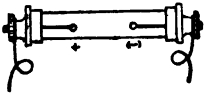

Fig. 120.

In subsequent charges, and when they are in use, it is only necessary to charge until the voltage rises to 2·5 volts per cell. It is advisable to charge the cells once a week at least.

Discharging.—The cells may be discharged through the lamps down to 1·8 volt per cell; but it is better to stop short of this in order to prolong their life. When discharged, the positive plates get a chocolate and the negative a light slate colour. When the cells are too much discharged they tend to get covered over with an obdurate sulphate of lead (Pb_2SO_5), sulphating is set up and its attendant evils, which ruin the cells. The "L" type of cells discharge at the rate of 4 amperes per + plate. The "K" type about 8 amperes per positive plate. Some cells stand from 800 to 1,000 discharges. For private electric light installations the "L" type of cells of the E.P.S. Co. are often used, each containing from 15 to 23 plates.

The following rule is given in Munro and Jamieson's "Pocket-Book" to show how long cells should be charged: "Before starting, take the sp. gr. of the cells—say it is on an average 1,170, and that there is a 6° rise during 1 hour's charge; then, if the acid turns milky at 1,210, it is necessary to charge for 6½ hours, for $\frac{1,210 - 1,170}{6} = 6{\cdot}6$ hours."

When there is a bad cell in circuit we should keep it out when discharging and put it in circuit when charging, and the simplest way is to disconnect one terminal of the cell and connect the two adjoining cells by a piece of cable long enough to carry the discharging current past the bad cell. When charging we can join them up to the bad cell as before.

The following table is given on p. 493 of "Electric Lighting and Power Distribution," by Maycock, and may be useful here:—

"Circuit Pressure.	No. of Cells.	Minimum Dynamo P.D.
50 volts	28 (1 cell extra)	70 volts.
100 volts	56 (2 cells extra)	140 volts.
200 volts	111 (3 cells extra)	278 volts.
240 volts	134 (4 cells extra)	335 volts."

Capacity.—The charging current varies according to the make of cell from 4 to 8 amperes per square foot of plate surface. The ampere-hour capacity depends on the number of ampere hours charge and discharge, and multiplying by the voltage of the battery gives the watt-hour capacity. A battery with a capacity of 500 ampere hours means any product of amperes and hours which come to 500, so that it can be charged or discharged at different rates. Thus a cell with a charging capacity of 500 ampere hours might be charged in 10 hours with 50 amperes, or in 5 hours with 100 amperes theoretically, but the cell would be destroyed by the heavy current.

Storage cells are manufactured for different purposes.

Stationary cells, those which are used for lighting and motive-power purposes.

Small and light cells which are portable.

Traction cells, those which are actually carried by the vehicle which is propelled by them.

Batteries in large electric supply stations are used to take the peak of the load; to act as balancers on the three-wire system; to save running the plant during early morning hours and on Sundays; and for substation supply purposes.

We take the cost of a storage battery at about £8 per kw., and the equivalent in boiler, engines, dynamos, and auxiliaries at £21 per kw. The present life of batteries does not exceed ten to eleven years; whereas the mean life of a generating plant we take at twenty years. So the capital charges on a storage battery are practically twice as heavy per kw. as those on a generating plant.

An *accumulator regulating switch* (see Fig. 121) is used to increase or decrease the number of cells charging or discharging through the circuit. A radial contact-arm, CA, makes contact with several blocks, C, to which are connected conductors going to the regulating cells RC. By means of this switch, we can cut out one to three or more cells, in order to regulate the e.m.f. of the battery; for instance, when all the cells are

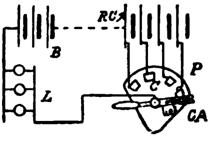

Fig. 121.

freshly charged, we can cut out the regulating cells, and add them as required to maintain the voltage.

Suppose a dynamo charges a set of storage cells. Let $E =$ the P.D. at the dynamo terminals and $e =$ e.m.f. of cells, and $r =$ their resistance, C going into the cells $= C = \frac{E-e}{r}$. So long as $E>e$, $E-e$ is $+$, and the cells receive a charge; but if, owing to lowering of the dynamo speed, e becomes $> E$, then $E-e$ becomes negative, and the cells will discharge through the dynamo, and drive it as a motor.

Voltage $E = Cr + e$. Power $EC = C^2r + eC$.

Exercise.—A shunt dynamo charges 50 cells. Resistance of leads and cells $= \cdot 5$ watt and counter-e.m.f. of each cell $= 2 \cdot 3$ volts. What is P.D. at the dynamo terminals to produce a current of 10 amperes?

$$E = Cr + e = 10 \times \cdot 5 + 50 \times 2 \cdot 3 \quad 5 + 115 = 120 \text{ volts.}$$

How many storage-cells of the "K" type (E.P.S.) are required to light 30 lamps of 16 c.p. each at 100 volts? Each lamp takes, say, 4 watts per candle-power; therefore, a 16-c.p. lamp requires 64 watts; for $4 \times 16 = 64$ watts.

$$\text{Current taken by each lamp } C = \frac{W}{E} = \frac{64}{100} = 0 \cdot 64 \text{ ampere.}$$

So 30 lamps require $0 \cdot 64 \times 30 = 19 \cdot 2$ amperes. Each cell gives 2 volts; therefore, $50 \times 2 = 100$ volts, so we find 50 cells are required, but allow three or four more to overcome the resistance of the conductors and switches. The dynamo used for charging should be a shunt-wound machine, and when ordering should be specified as able to give 2·5 volts for each cell to be charged in series in the battery.

CHAPTER XII.

ARC LAMPS—INCANDESCENT LAMPS.

I. **Arc Lamps.**—In 1812 Sir H. Davey used a battery of 2,000 cells, and by connecting them to two pieces of light wood charcoal produced a very brilliant light, or arch, which was said to measure 5 inches in length. When any substance was introduced into this arch it became incandescent. Platinum melted, sapphire, magnesia, and lime were fused, pieces of diamond and granite rapidly volatilised. The arched form taken by the luminous particles of carbon resulted from the upward rush of heated air. The term arch in its abbreviated form "arc" is still retained as the name of the luminous space between the carbons.

Professor Dumas repeated the above experiment in Paris, in 1834, and predicted its final success as an illuminant, but at that time the cost was prohibitive. In 1845 Staite and Foucault independently invented a mechanism for regulating the distance between the carbon points. In 1862 Faraday introduced the arc lamp into a British lighthouse, and Paris was lit up by a form of arc lamp called "Jablochkoff candles" shortly after this.

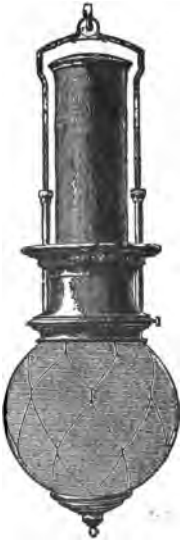

Fig. 122.

Fig. 122 shows the external appearance of an arc lamp.

Arc Lamp Mechanism.—The different varieties of lamps have various mechanical arrangements for feeding the carbons forward, and we have selected the Pilsen arc lamp for a description, and of which a diagrammatic representation is given in Fig. 123. The current at the junction A divides into two paths, one of low resistance and the other of higher resistance. The former is the striking or thick wire coil in series, SC, through which current passes by the contact roller R and lamp mechanism to the upper carbon holder UCH, the circuit being completed through the arc and lower carbon holder. The other path leads to the shunt coil S*h*C or feeding circuit, composed of fine wire coils, having its ends attached to A and LCH (the lower carbon holder). The coils are wound on a drum, inside of which a brass tube fits loosely, so that it can slide up and down. Inside this again is a soft iron core, C, shaped like two long cones, set base to base. This is nearly balanced by a weight, W, attached to a cord, passing over a pulley, P, at the top of the lamp. When current is started it goes nearly all through SC and the carbons, which are touching each other. The coil now attracts the core and sucks it upwards, thus separating the carbons and starting the arc. The coils, SC and S*h*C, are wound so that their respective resistances are adjusted, in order to cause their actions on the core to be balanced when the arc is struck and burning properly. When an increase in the length of the arc takes place, this disturbs the balance and increases the resistance in SC, so more current passes through S*h*C, and the core, with the upper carbon attached to it, is sucked downwards and again restores balance, as well as adjusting the arc to its proper length. This arrangement acts well, and the two coils act and react on each other, so that there is no apparent fluctuation of the light set up, and the two carbons are kept at a proper distance apart. Lamps are also made with ordinary cylindrical cores. Arc lamps give from 1,000 to 2,000 candle-power, and require from 5 to 10 amperes, at say 45 to 60 and 80 volts. They are

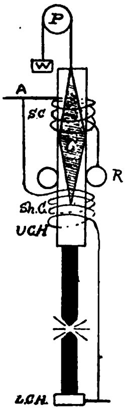

Fig. 123.

classified into constant-current and constant-pressure *Open Arcs*, and constant-current and constant-pressure *Enclosed Arcs*. The former are used for street-lighting on a high potential circuit. "*Carbons* are composed of powdered coke, calcined lampblack, syrup and water, being moulded and dried in a crucible." See Munro and Jamieson's "Pocket-Book."

In a *continuous-current open type lamp* the + or upper carbon is consumed twice as fast as the (–) carbon, and a crater forms (Fig. 124). A well-formed crater means a steady light. The bottom carbon is always the smaller of the two. About 80 per cent. to 85 per cent. of the light is said to come from the + carbon, and the remainder from the (–) carbon. The temperature attained by the + carbon is about 3,500° C., while that of the negative carbon varies from 2,100° C. to 2,500° C. In a 50-volt lamp a properly developed arc cannot be maintained with a voltage of less than 44 volts between the carbons —39 volts are required to get an arc at all. The + carbon only is cored.

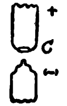

Fig. 124.

As we have just seen that, with direct current, the most of the light comes from the crater of the + carbon, so, if the lamp be inverted, the most of the light is thrown downwards from the ceiling (when used for lighting interiors), and a diffused and almost shadowless light can be got in this way.

Arc lamps are used for lighting streets (say 20 feet from the ground in height, and at distances of from 60 to 100 yards apart for a 10-ampere arc), yards at public works, railway stations and goods yards, public buildings, mills, engineering works, shops, and warehouses. In former days arc lamps were run in series on a circuit, but now they* are put in parallel series

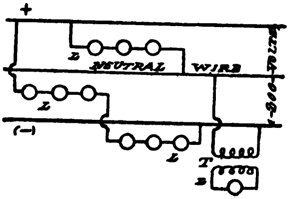

Fig. 125.

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* This refers to a double-carbon open type arc lamp.

(Fig. 125), being joined in series of two across parallel mains on a 100-volt, or four on a 200-volt main; or nine open-type arcs on 480-volt mains. In series each lamp, and in parallel series each group of lamps, must have a resistance in circuit with them. By providing an automatic cut-out in the lamp itself, or in the base of the pole for each lamp, the accidental coming together of the carbons on one lamp, or its failure from some other cause, does not affect or short-circuit other lamps. The arrangement is as follows (Fig. 126). There is an electro-magnet EM, wound with fine wire, which is inserted as a shunt in circuit between the point P, where the main current enters the + carbon holder H, and the negative terminal T (–). If the lamp fails to work, the voltage between the terminals of EM rises and sends sufficient current round to magnetise the core C, the armature A is attracted, a spring, SP, automatically closes the circuit, and the lamp is cut out; but, at the same time, a resistance is substituted for the lamp that is cut out. There must also be an isolating switch in the base of every pole.

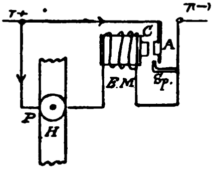

Fig. 126.

Alternating-current arc lamps have their magnet cores laminated. The coils have also a larger number of turns than in direct-current lamps, because of the smaller magnetic effects of the current. They have a lower efficiency, and give out a rhythmic hum when burning properly. Both carbons burn away equally, and the light emitted is purplish in colour. The consumption of both carbons is about the same, and this varies with the alternations of current.

One of these lamps will burn steadily with an e.m.f. at its terminals of from 36 to 40 volts, so that two can be run in series on a 100-volt circuit. The open type of lamp (having air surrounding the arc) is used for outside lighting. The light emitted for a given amount of energy and the true fficiency is greater than in the enclosed type, and each lamp requires re-carbonising very often.

The *enclosed arc lamp* has a small glass receptacle, more or less air-tight, in which the carbons burn,* and this forms a partial vacuum, and, there being less air, combustion is much slower. Consumption of carbon is much less than in the open type, and it will burn from 100 to 150 hours, and require recarboning once a week.

Double-carbon arc lamps are much used for street lighting. They can be joined across a 110-volt circuit, or put in pairs across a 220-volt circuit. Each consists of a combination of two independent regulating devices on a common base, so that when one set of carbons burn down, the other pair come automatically into action.

There are many different varieties of make of lamps on the market, such as the Brockie Pell, Gülcher, &c.

Searchlights are special arc lamps of great power, requiring from 30 to 150 amperes at 55 volts, and are provided with projecting lenses or mirrors.

The flame arc lamp has lately been introduced by the Union Electric Co. The carbons are impregnated cones, containing salts, which give an orange tinge or pale golden colour to the light. The distance between the + and (–) carbon is about ½ inch. An inverted fireclay cup partially encloses the arc, the + carbon passes through a hole in the cup, and the heated vapours round the arc accumulate in the cup and prevent oxygen reaching the + carbon, so it can be made smaller than the (–) one. The cup reflects the light downward, and this is increased by the deposit of a brilliant white powder upon it, from the salts inside the cores of the carbons. This arc, though ½ inch long, only requires 43 volts, with a current of 9 amperes. Four of these lamps will run on a 200-volt circuit.

The *miniature arc lamp* is made for outdoor or indoor use. Length is 16 inches over all. The carbons burn from 18 to 22 hours. It can be joined up singly on a 100 to 120-volt circuit, or two in series on a 200 to 250-volt circuit. The current varies from 1½ to 2½ amperes, and the lamp consumes about 1 watt per candle-power.

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* Sometimes an enclosed arc lamp has both carbons of the same diameter, but the +, or upper carbon, is twice the length of the (–) carbon in this case.

Messrs Johnson & Phillips make a lamp called the "*Ark*," which can be readily adapted for all circuits, alternating and direct-current, and for parallel and series working. There are two coils supplied, and in converting this lamp one coil is exchanged for the other one.

II. **Incandescent Lamps.**—In 1841 an Englishman called De Moleyns applied the principle of incandescence in a vacuum with a platinum wire. In 1848 Petrie took out a patent in Great Britain for preparations of iridium for lighting purposes. In 1853 De Changy brought a spiral of platinum wire to incandescence. An American called Starr originated the idea of using carbon to produce incandescence, and his lamps were shown in 1845. Swan, in Newcastle, and Edison, in America, within recent years brought the incandescent lamp to its present state of perfection. They are used for lighting up the interiors of buildings, and consist each of a thin carbon filament, inside an exhausted glass bulb. The connections between the carbon and the external conducting wires are secured by short pieces of platinum wire, fused through the glass. The passage of a current causes the filament to be raised to a white heat, and it becomes intensely luminous, and the remarkable thing about the filament is that its resistance to the passage of current decreases as its temperature rises (the opposite with metal conductors), *i.e.*, the hotter it is the less current is required to keep it incandescent. The filament of the Swan lamp is composed of cotton thread, or made from thread formed by squirting a solution of cellulose through a fine nozzle. This cellulose is an ingredient of vegetable substance, such as cotton, linen, paper, &c. The filaments are now made of the best asbestos cotton. Raw cotton is treated with chloride of zinc, and it becomes a pulpy mass. This is squirted through platinum dies of different sized openings according to the kind of lamp required; next hardened in alcohol and hydrochloric acid, and then put in a crucible packed with graphite at a temperature of 4,500° F. When carbonised it is ready for mounting. Platinum wires are used in mounting the filaments, as this metal expands at the same rate as glass without risk of fracturing the glass on cooling.

Lamp manufacturers are now using the minimum quantity of platinum wire in lamps; they have tried to find a substitute for it, but no effective one has yet been discovered that we know of.

Filaments are shaped either as single or double loops, and the finer the loop is, the greater is the resistance, and the greater voltage it takes to send current through it. Lamps are made to give any required degree of illumination from 1 c.p. up to 2,000 c.p. For ordinary lighting purposes lamps of 8, 16, 32, and 64 c.p. are the sizes mostly used, and at voltages from 50 and 100 up to 250 volts. 16-c.p. lamps take 60 watts each, at 100 volts they take 0·6 ampere each, and the higher the pressure the less current they take. At 200 volts a lamp takes 0·3 ampere, and at 250 volts 0·24 ampere.

The life of a lamp varies: some filaments only last a few hours, others last for years. The life depends on the strength of current sent through it; the feebler the current the longer it lasts. Lamps are mostly run in parallel (Fig. 127), not in series, as in the latter case if one fails the circuit becomes disconnected, and all go out. When in parallel, only that lamp or lamps go out that are in the branch circuit. Should one get burned out, all the rest keep lighted on other circuits. Again, as the total P.D. between the mains is only that for one lamp—viz., 100 volts or 200 volts—there is not the same risk of the attendant getting an accidental shock of a serious nature.* They are also run in multiple series (Fig. 128). Groups may consist, say, of four lamps, each taking 0·3 ampere; another group of, say, six lamps, each

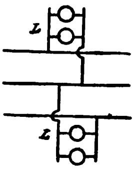

Fig. 127.

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* Lamps in tram cars, &c., are nearly always run five in series.

taking 0·2 ampere; and another group of two lamps, each taking 0·6 ampere. So that it is possible to have lamps of different candle-powers in circuit; but each group must consume the same amount of current, so that balance may be got.

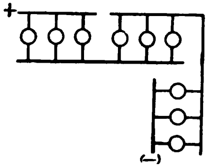

Fig. 128.

Incandescent lamps are well fitted for domestic lighting. They have no smell, do not vitiate the atmosphere, or raise the temperature of a room, are easily lit and extinguished by simply turning a switch, there is little risk of their setting fire to anything, and with a steady e.m.f. at their terminals they give a steady light; hence they are suitable for lighting the interiors of houses, railway carriages, ships, mines, and for use by divers (as they burn well under water), for surgical purposes, and electrical testing.

Candle-power.—By the candle-power of a lamp we mean its luminosity as compared with a standard candle weighing six to the pound, and made to burn 120 grains of spermaceti wax per hour; length of candle is 8¼ inches to 9 inches. (This is the English standard.) Lamps, after being manufactured, are standardised by photometers, and their candle-power noted. "As a rule, in rooms 10 feet high, a 16-c.p. lamp placed about 7 feet from the floor effectively lights 100 square feet of floor area" (Munro and Jamieson's "Electric Pocket-Book").

In many places, high-voltage lamps are used, each taking current at 250 volts. These high-voltage lamps are said to be a little less efficient than lamps of lower voltage.

It has been found that, by taking a 16-c.p. lamp as the standard, two 16-c.p. lamps, or one 32-c.p. lamp, per 100 square feet of floor space, gives good illumination; three are much better, but four are brilliant; of course these effects are modified by the height of the ceiling, colour of the walls, &c. When white, few lamps are required. In halls, public buildings, &c., some electricians divide the ceiling into squares, and put a lamp in the centre of each, the size of square depending on the height of the ceiling.

Double-filament lamps are for high voltages, *i.e.*, 200 volts or more; then the filaments are put in series. Sometimes they are in fine double filaments, or with a very long single filament, and when curled they are anchored to the glass by platinum wires to prevent them colliding with each other or with the glass, for if they touched when current was passing through them they would break; 500 and 2,000-c.p. lamps are parallel-filament ones. (See Fig. 129 for different types.)

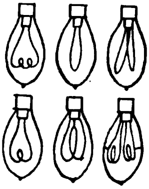

Fig. 129.

Lampholder.—In small lamps the outer ends of the platinum leading-in wires are simply bent into two small loops, a holder for these being provided with two spiral springs connected to the circuit leads. The free ends of the springs pass through the lamp loops. The base of the glass bulb fits into an outer stronger spiral, which is of just sufficient strength to keep the lamp in good electrical contact with the spirals; but this lamp is apt to be shaken out of contact if there is much vibration. The commonest form of holder is where the lamp is provided with an insulated brass collar, fixed on with cement, the filament being connected to the two brass segments, and embedded in cement. This collar has two small pins which fit into the "bayonet-joint" holder; it is mounted on a porcelain base; through this pass the connecting wires, which are clamped one to each plunger. A small spiral spring keeps each out as far as it will go. On twisting a lamp into the holder the segments rub, and so make contact with the two plungers, and the lamp is put into circuit by the act of fixing it in the holder. There is another form of holder called the Edison "Screw" holder.

Exercise.—How many 16-c.p. lamps can be run by a 20-E.H.P. dynamo? Each lamp takes 3·5 watts per candle-power—theoretically, better say 4 watts. Then one 16-c.p. lamp takes $16 \times 4 = 64$ watts. 20 E.H.P. $= (746 \times 20 = 14{,}920$ watts)

$$\therefore \text{No. of lamps} = \frac{14{,}920}{64} = 233.$$

At 5d. per B.T.U. what is the cost to run ten 16-c.p. lamps for six hours?

Energy expended—

$$\frac{10 \text{ lamps} \times 16 \text{ c.p.} \times 4 \text{ watts} \times 6 \text{ hours}}{1{,}000} = 3{\cdot}84 \text{ B.T.U.}$$

$$\therefore 1 \text{ B.T.U.} : 3{\cdot}84 \text{ B.T.U.} :: 5\text{d.} : + = 1\text{s. } 7\text{d.}$$

The *Nernst lamp* has lately been put on the market. It was invented by Dr Walther Nernst, of Göttingen University, Germany. The filament consists of a highly refractive oxide (rare earths, thoria, tria, zirconia; also magnesia) instead of carbon. This is an insulator when cold, but when heated it becomes a conductor, and stands a higher temperature than carbon, so it can be run at a higher efficiency. A vacuum globe is not required, as the oxides are not consumed. The early form of small lamps had to be heated by a spirit lamp or a match, but now automatic heaters are used. The filament F is horizontal (Fig. 130); sometimes it is vertical. Surrounding this is the heater H, consisting of a long fine platinum wire wound on a porcelain rod and bent by the blowpipe into a spiral shape. There is a steadying resistance of fine platinum wire R inside a glass tube put in series with the filament to steady the current. When current is turned on, it passes round the spiral H by the keeper K. When the filament gets sufficiently hot to conduct current, the spiral is automatically cut out of circuit by the action of the electro-magnet EM upon its keeper K; this flies off, and current must pass through the resistance R and filaments F. When this happens F becomes incandescent. The efficiency is said to be about 1·5 watt per c.p. The filament being an electrolyte, the current must pass through it in one direction only, and it must be properly joined up. In alternating circuits it can be joined up any way.

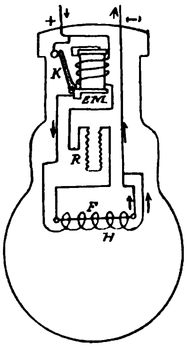

Fig. 130.

These lamps are now being used for lighting up the interiors of shops and offices, as well as being put on street arc lamp-posts in some towns, to take up the lighting after the arc lamps are switched out of circuit, about midnight. Their life varies greatly; some last 800 hours, and others not 20 hours, and it appears that failure mostly results from mechanical fracture of the glower, or heater (a delicate piece of mechanism). Lamps take ¼ and 1 ampere up to 250 volts, and ½ ampere up to 150 volts.

The *Cooper-Hewitt Mercury* vapour lamp is an American invention. The lamp consists of an exhausted glass tube, ranging from 3 inches to 12 feet long, requiring 0·2 ampere to 20 amperes from 50 to 100 volts. Mercury is put inside the tube, and it gets filled with an invisible vapour, and when current passes through, this emits a brilliant light. The life is practically infinite, since there is no actual consumption of vapour. It is usual to disconnect each lamp after from 1,200 to 1,400 hours' use, open the tube, wash it, re-exhaust, and we get a lamp as good as ever. The light contains no red rays, and owing to this fact the human face appears to lose its flesh tints, and the lips get livid when seen by it. It is rich in chemical rays and is very valuable for photographic purposes, it is also used as an illuminant in workshops, factories, drawing-offices, &c. The candle-power may be as high as 500.

A lamp now exists which is held to be an improvement on the above, and is known as the *Bastian*, in which an attempt has been made to supply the red rays which are wanting in the Cooper-Hewitt lamp.

The *Osmium lamp* is being introduced by the General Electric Co. This is a metal allied to platinum, and has a comparatively low resistance, but the filament is longer than in ordinary incandescent lamps. The energy consumed is said to be about 1½ watt per candle-power. Good for low voltages as 25 to 30 volts.

The *Tantalum lamp* is being introduced by Messrs Siemens & Halske (Germany). The metal is a rare one, and has some of the properties of steel, with a high resistance. A very long filament is used: a 100-volt lamp has a filament fully two feet long, and this is wound zig-zag on glass supports, inside a glass bulb, and the lamp is not much larger than an ordinary incandescent lamp. The energy consumed is from 1½ watt to 2 watts per candle-power.

Photometry.—The instrument used for determining the relative intensities of lights is called a photometer. There are different forms of this instrument—such as Rumford's, Bunsen's, Ritchie's, Limmer-Brodhun, Jolly's, Sabine's, &c.

Bunsen's P. consists of a square wooden frame, on which is stretched a sheet of white paper, having a grease spot in its centre (Fig. 131). This frame slides along a scale, SC. At one end is fixed a standard 16-c.p. lamp, and at the other the lamp to be tested. Regulating resistances are put in series with both lamps, and current is drawn from accumulators, as the pressure is steady. Wattmeters are used to determine the lamps' efficiency. Regulating resistances keep the voltage the same in both lamps, as recorded on a voltmeter with a two-way switch. The paper is then moved backwards and forwards between the lights until the grease spot GS disappears, as seen from either side; for, if the light be stronger on one side, on looking from that side the spot will appear dark, while from the other side it will look bright.

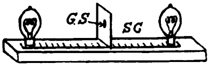

Fig. 131.

Next measure the distances from the lamp. Let the distance from the standard lamp to the paper be x, say 12 inches, and from the experimental lamp y, say 4 feet. Now the candle-power of the lamps is in direct proportion to the squares of the distances. Let CP be the unknown candle-power. Then—

$$16 : \text{CP} :: x^2 : y^2 \text{ or } 16 : \text{CP} :: 1^2 : 4^2 = 1 : 16$$

when the shadows are equal, *i.e.*, the light emitted by the experimental lamp is sixteen times as strong as that from the standard lamp.

Another form of photometer consists of a square wooden box (Fig. 132) with sides only, painted black. Fixed vertically in this box are two sheets of white cardboard, with a hole in one piece, H, set at such an angle that, looking through the sight-hole S, both pieces are seen; the lower one through H. The light from the lamps is allowed to shine on the cardboard slips from either side, and by careful manipulation a good comparison is made by adjusting the position of the photometer, so that the light reflected from both pieces of cardboard is the same, *i.e.*, the hole becomes practically invisible. All these experiments must be conducted in a dark room.

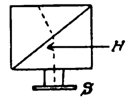

Fig. 132.

Incandescent lamps are tested generally with a Weston ammeter for current, and a Kelvin multicellular voltmeter for volts in order to get the watts. The General Post Office uses Trotter's photometer to find the candle-power. The Hefner amylacetate lamp is taken as the standard in Germany; its c.p. equals 0·88 English candle.* Sir William Preece's test: a 100-volt lamp is subjected to 170 volts pressure for 2½ minutes, a 200-volt lamp to 340 volts for 2½ minutes, and so on, in proportion. A good lamp will stand this pressure. Candle-power and watts per candle are again measured, and the less the c.p. and efficiency have fallen off, the better is the lamp.

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* This test would only be applied to a sample lamp.

CHAPTER XIII.

SWITCHES, FUSES, ETC.

Switches.—The *main switch* on a circuit resembles the main gas-cock in a gas supply. When open, it cuts off all connection with the outside main cables, or the dynamo in a private installation, and it should be made double-pole so as to sever both mains at the same instant. Switches are made in different sizes, according to the amount of current they carry, and are called 25, 50, 100, or more, ampere switches. Voltage does not affect the carrying capacity of a switch, though it affects the design. A switch carrying, say, 50 amperes, at 100 volts, will be differently constructed from one carrying the same current at, say, 500 volts. With high voltage current the handle should be well insulated, and the distance through which the arm travels, when breaking current, or opening the circuit, should be far enough to prevent a spark passing and setting up an arc, as this might cause a fire, besides damaging the contacts. If there is a high e.m.f., and the current is suddenly switched off, there is apt to be considerable sparking across the air space, as the current tries to go on its course, and so volatilises part of the metal contacts, and may set up an arc. Generally the switch handle is thrown off quickly by means of a spring, so that the lever is either completely on or off, and in this way an arc cannot start readily. The switch base is of insulating material, such as slate, marble, or porcelain. The cables are not clamped, but have their ends soldered into thimbles which can be bolted to the switch-board. Main switches are of two kinds, *single-pole* or *double-pole*, and these may be again *single-break* or *double-break*. A *single-pole* switch severs one main only, a *double-pole* switch severs both mains. A *single-break* switch breaks the main at one point only, a *double-break* switch at two points. In Fig. 133 SPSB is a single-pole single-break switch; DPSB is a double-pole single-break switch; SPDB is a single-pole double-break switch; DPDB is a double-pole double-break switch; SPM is a single-pole multiple-contact switch; DP2way is a double-pole two-way switch; TPDB is a triple-pole double-break switch. For domestic lighting, main and local switches are used. Main switches are placed on the main distributing-board, either single or double-pole, to control the various circuits running therefrom, as well as the whole installation. The "*Chopper type*" consists of laminated copper strips, and a spiral spring controls the spring-off action under the handle; adjustment must be made for wear. The handle consists of hard wood, and the switch is joined to the circuit by sweating-thimbles, the studs of which project through the base and screw into a fixed contact with locking nuts. There is an independent porcelain or slate base; but this is dispensed with on a main distributing-board when the switches are mounted thereon. They are mostly single-pole (Fig. 134); but double-pole main switches generally consist of two switches permanently joined together by vulcanised fibre, so that both go on and off together to break or make circuit simultaneously at both poles; or two such switches can be arranged in tandem (Fig. 135).

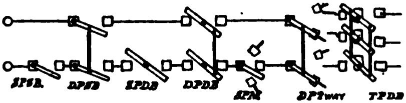

Fig. 133.

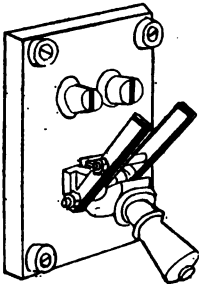

Fig. 134.

Local Switches are of the "tumbler" type. The base consists of porcelain, and the handle or "dolly" is directly jointed to the contact arm, by which good action is got. In the best class of switches the handle is made of ebonite, and they are enclosed in a case with polished teak sides and glass front, and there must be an indication of the "on" and "off" position. Each must have a sufficient length of break for the voltage used. A pull switch is like a tumbler switch: there is one cord sometimes, and successive pulls on this put the current alternately "on" or "off." There is a contact pivoted arm which has an angular projection on its upper edge; when the vertical rod is pulled down by the cord against a spring, a pin on the under side of its upper end works to one side or other of the projection, and forces the contact arm "on" or "off." Two-way switches are used for turning off and on a lamp from one of two points. In them there are two terminal pillars joined together by metal bars. Those form the common terminal; another terminal is placed in front, and the remaining one behind the handle. In central stations the principal forms of main switches used are the lever, the knife, the plug, and the sliding switch.

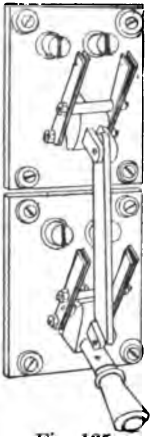

Fig. 135.

The lever switch (Figs. 134, 135, 136) consists of an arm pivoted at the middle or at one end, which can be moved to right or left in a plane parallel to the board, or from the board in a plane at right angles to it.

The knife switch (Figs. 134, 135) makes and breaks contact generally at right angles to the switch-board. An insulating arm, having the conducting parts attached to it, is moved backwards and forwards, making contact at one end of its range and breaking it at the other, the direction of motion being at right angles to the board. Most of the low-pressure switches are of this type. Ferranti's switch is an example of a knife switch used upon a high-tension board.

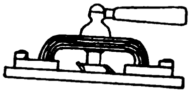

Fig. 136.

The Plug Switch.—There are fixed sockets on the switchboard connected together, and these are electrically connected by the insertion of a separate part consisting of an ebonite slab with an insulated handle and metallic plugs (there are four), with metallic strips connecting them together. Thus the break depends on the operator only (Fig. 137). In the Lowrie-Hall form for high pressures (Fig. 137) a slate base carries four porcelain blocks, in the centre apertures of which the sockets A, B, C, D are concealed. At the back the sockets join the conductor terminals. Split plugs, E, F (there are four), are mounted on an ebonite slab, E*b*, with handle and stop piece, SP, to prevent the plugs going in too far. Two of the sockets are of one polarity and two of another; say, A and B are the inner and outer bus-bars, and CD the poles of the machine, and the plugs join the like poles together. This switch is practically obsolete.

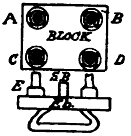

Fig. 137.

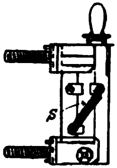

Fig. 138.

The sliding switch is used where not only a circuit has to be made or broken, but where a transposition of connections is required, and the number of contacts requires a long range of motion.

There is also a combination of switch which is partly of the plug and partly of the knife pattern. Ebonite insulation is used, with a slate base. With high-pressure currents, on breaking a circuit, an arc is always drawn out between the contacts, and to prevent damage it must be extinguished soon after formation; but the difficulty to do this is greater with continuous than with alternating currents. It is usual to provide a long break, and have the break effected very quickly. Hence mechanical devices are used to cause the contacts to fly apart very rapidly. In *the Thomson-Houston switch* (Fig. 138) a flat blade passes in between a pair of flat surfaces, having saw-cuts in them. The blade is divided into two parts, hinged to each other and held together by a spring. On making contact, both pieces act as one only; but on breaking circuit, the friction of the encircling tongues holds one of the pieces tight, and the other, leaving it behind, extends the spring s. When a certain tension is attained, the friction is overcome, and the piece flies off very rapidly. Another method used to diminish the amount of vapour formed consists in substituting two carbon blocks for the metal; but to ensure good contact, the carbon is supplemented by metallic contacts, which make contact after the carbon, and break before it. In fact, there are two switches—the carbon one making and breaking the circuit, but carrying little current, and the metallic one, which carries about the whole of the current. With pressures from 500 volts to 2,000 volts these can be readily dealt with, but from 5,000 volts and upwards the question is a very difficult one.

Fuses—Cut-outs, and Circuit-breakers.—The use of these is to prevent damage to the dynamo, leads, or buildings, from overheating caused by too strong a current passing. They give protection by automatically disconnecting the circuit whenever the current, from some cause or other, exceeds the normal working current by 50 per cent. They are of two kinds: (1) Those carrying a special wire which melts with a current of a definite strength. (2) Those actuated by an electro-magnet. The bit of wire or fuse must have a low melting point, and must rapidly break, whenever current rises too high. Tin is the best metal for a fuse, as it is durable, and melts at 235° C. The base on which the fuse is mounted should be of incombustible material, such as slate or porcelain, and be protected by a brass or porcelain cover. "Main" fuses are of large size for protecting main cables or "branch" for protecting lamp circuits. They are divided into *double-pole* and *single-pole*. A *double-pole* cut-out (Fig. 139) has a fuse in both the + and (–) wires, and is used on all main circuits and all circuits

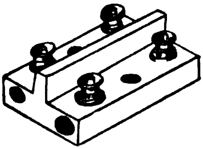

Fig. 139.

tapping directly into the mains, as this gives complete protection. In lamp circuits we often use *single-pole* cut-outs (Fig. 140) as being sufficient to protect against ordinary risks. Cut-outs are generally called by the current-carrying capacity of the lead fuse wire they are constructed to hold, and are called 1 to 5, 5 to 10 amperes, or as main ones, 20-, 50-, or 100-ampere cut-outs. In an electric-lighting installation main fuses should be put as near the terminals of the source of supply as possible, so as to leave a very short length unprotected. They should also be put where a branch is tapped off a pair of mains, and whenever a conductor is reduced in size, because a smaller wire would get overheated by a given current, when a larger wire would safely carry it. Each lamp must also be protected by a fuse, and if there be a switch for each lamp the fuse should be put in the switch or in the ceiling rose. But we must remember that every cut-out becomes more or less an additional source of breakdown, and that each is also an additional point to earth.

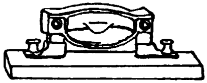
Fig. 140.

The rule given by the Institution of Electrical Engineers is, "That all switches and fuses ought to open circuit safely with 50 per cent. excess current over the rated current on a circuit of a P.D. of 50 per cent. in excess of the normal." A fuse-board is often erected so as to bring all the fuses in one place, so that they can be more easily renewed. They are all single-pole or double-pole; but two separate single-pole fuses are preferable to one double-pole fuse. Each fuse may be enclosed in a cast-iron box, with glass front, and the leading-in holes bushed with ebonite; or, if two fuses be put in one case, a dividing porcelain partition is fixed between them, the case being lined with asbestos, and having a glass front, sweating sockets being placed in front of the insulating base. Cast-iron covers should be earthed to the nearest water pipe.

The proper position for fusible cut-outs is wherever, in numerous bifurcations, there is a change of gauge in the conductor used.

A Fuse-Board collects all the various fuses together which control the installation, or a part of it, such as one of the floors of the house. There may be fuse-boards on each floor, from which a distinct group of circuits branch off, the + and (−) mains, being attached to vertical bars. From the bar marked + current flows through the various fuses to the lamp circuits, and returns also through fuses to the negative bar. Double cut-outs afford better protection than single ones to the lamp circuits. The boards are usually double-pole with milled nut fuse terminals to hold the fuses, or are provided with spring-clip bridge pieces (Fig. 140).

It is often inconvenient to replace a fuse which has blown without first throwing off the switch; otherwise, sparks would arise when putting the fuse-wire under the terminal. Hence these spring-clip bridge pieces are used to get rid of this difficulty, as the fuse-wire can be inserted in the removable bridge, which is then put back in its place.

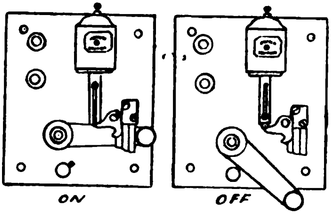

Fig. 141.

Automatic Cut-outs, or **Circuit-breakers** (Fig. 141), are convenient for circuits where the fuses are likely to blow frequently, and they can be rapidly reset. Their action is based on the increased current passing through them more powerfully energising an electro-magnet, thus causing it to attract its armature, and so sever the circuit by pulling the switch-lever off its contact, and then no current can pass (see p. 45 and Fig. 42). Some of these devices will open in about $\frac{1}{100}$ part of a second if the excess current is heavy. There are also circuit-breakers made for interrupting at overload, or for reverse currents, or even for both overload and reverse currents.

A few notes on high-tension fuses may be of use. The greater the e.m.f. the greater must be the length of fuse to prevent an arc forming; also it must be the greater with increased current at the same e.m.f. A fuse length, safe at 50 amperes, is unsafe for 150 amperes. The section must only be small enough to allow of quick action. A 1½-inch gap is allowed for voltages of 150 to 200 volts; above that a gap of 3 inches to 4 inches is allowed according to circumstances. For 2,000 volts a break of 30 inches is not too long on a main fuse unless the arc can be extinguished, such as under oil. With high-tension fuses for safety in handling, and to ensure blowing at the right moment, the wire must be enclosed. If a straight tube with terminals at both ends be used, it must be made very long to destroy the arc. So Mordey, to reduce the length, invented his well-known dust-fuse (Fig. 142). The wire is enclosed in a glass tube, and passes through marble dust and sand cement at each end. This refractory insulating material fills and prevents the arc travelling outwards to the contacts, and absorbs the volatilised metal. For large currents it is used as a shunt to an ordinary fuse, so the final break occurs between the two parallel pellets of marble dust.

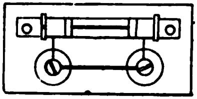

Fig. 142.

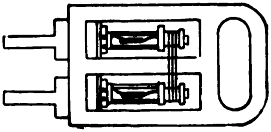

Fig. 143.

Ferranti's Oil Break Fuse (Fig. 143) consists of a rectangular porcelain vessel containing resin oil to a depth of several inches. It is divided lengthwise into two compartments. Each compartment has a spring which, when at rest, has its free end resting in the bottom. To set the fuse, the free ends of the two springs are raised till they are clear of the oil. Fuse-wires are then attached between the springs which join the terminals, and they rest on the dividing porcelain partition. When excess current flows the fuse-wire melts. This releases the two springs, which plunge down through the oil in each compartment, and this puts out the arc. This fuse will break from 500 amperes at 5,000 volts, and consists of a number of fine tinned copper wires, say 24 to 30 S.W.G., put in parallel between the steel springs.

Ceiling roses join the wires which run along ceilings, and a flexible cord pendant is suspended from each. The rose is made of the best English porcelain, with a dividing wall in the centre to keep the two opposite terminals apart. Some of them contain fuses; but this is not much approved of now, as ceilings are liable to vibration, and this tends to slacken the screws which hold the fuses. A high class type of ceiling rose is the looping-in pattern. It has extra large holes in the base-plate, to admit of two circuit-wires passing to each terminal instead of one only. This saves making joints, and is very satisfactory.

Wall plugs, each consists of two parts. The socket or *fixed* part, which has its terminals permanently joined up in circuit, and the *movable* part, called the "plug," which, by a flexible cord, connects to a table lamp or telescopic floor lamp, so as to be portable. When in use, the plug is pushed into the socket. Electrical connection is made by two pins or two concentric tubes. The first is called the "two-pin" type, and, from better insulation, these are suited for high-voltage work. Sometimes a fuse is provided, but mostly the fuse which controls the plug is at the distributing-board. Very often the flush pattern is used for appearance sake, where all the parts except the top plate are sunk beneath the surface.

Plugs must be of fire-proof material; the base of black or white porcelain. They are rated at 1 to 5 amperes, and for radiators we use a 10-ampere plug.

Blocks.—Ceiling roses, wall plugs, and switches are put on circular wood blocks of seasoned wood, teak or even mahogany. They are recessed at the back. Blocks are 1 inch thick, or ½ inch for concealed work. In plastered ceilings they are fixed by screws into the lath. On brick walls plugs are required to fix them.

The Switch-Board.—The definition of a switch-board is so clearly expressed in "Central Generating Stations," by C. H. Wordingham, that we give it here:—

"The switch-board is the most vital part of the whole system of supply, for to it converge all the internal work connected with the generating plant, and all the external systems of mains for feeding and distributing. . . . The primary object of a switch-board is to gather the current generated by the dynamo machines, and direct it, as desired, into the underground mains that convey it to the points of utilisation. . . . Secondly, it controls the pressure of supply and the appliances for enabling machines to be suitably brought into service. Thirdly, the instruments necessary for the measurement of the output of the generating plant, the indication of the power supplied to the mains, and its mode of distribution over the system, together with the measurement of the pressure at which it is supplied, form an integral part of the switch-board.

"Switch-boards fall broadly into two classes, viz., (*a*) those intended for *high pressures* and *moderately large currents;* and (*b*) those *for exceedingly large currents at low pressure*. . . .

"The *essentials* of all switch-boards are:—(1) The whole apparatus must be composed of incombustible materials. . . . Marble is better than slate (for the panels), but this last is most unreliable. . . . A switch-board should consist as wholly of metal as possible. If for high-pressure work, every particle of metal not forming part of the circuit should be connected efficiently with earth, and especially should all levers and other parts that have to be handled be kept most carefully at earth potential. . . .

"(2) All apparatus must be so disposed that there shall be no danger to life, whether from shock, fire, or mechanical force, during normal or abnormal working.

"(3) Every part must be calculated that it shall be free from heating when used continuously. . . . The organs of a switch-board are (1) switches, (2) circuit-breakers, (3) directing apparatus, (4) connections, (5) support and insulation of the apparatus. In addition to these there are, of course, the instruments, synchronising gear, &c."

Switch-boards in a private installation, or inside a building with a public supply current, are of two kinds—*main-boards* and *distributing-boards*. A *main switch-board* cuts off all communication with the outside mains, dynamo, and controls the whole circuit. It contains the main switches, ammeter, voltmeter, and consists of a backboard of mahogany, walnut, or teakwood, the surface of which is french-polished and the edges moulded. The switches and the rest of the apparatus, where sparking is likely to occur, must be mounted on a non-inflammable base, such as porcelain or slate.

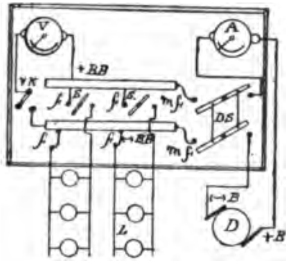

Fig. 144.

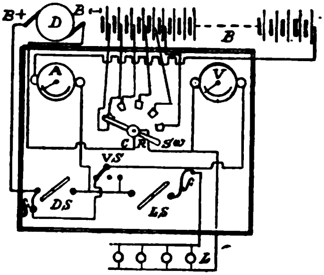

Fig. 145.

The simplest form of *main switch-board* (Fig. 144) is where there are no cells, only one dynamo supplying the lamps direct through a double-break single-pole main switch, DS, and double-pole fuses on to the bus-bars, positive +BB, (−)BB; one ammeter, A; one voltmeter, V; one voltmeter switch, VK; one double-pole main cut-out, *mf*; double-pole circuit-fuses, *f*; and switches, S. Here there are only two lamp-circuits shown, but there might be many more.

An *accumulator switch-board* is shown in Fig. 145. By the arrangement there given, it is possible to run the plant in four combinations. (1) Charging the cells by running the dynamo with DS on, and LS off, and CRS*w* full on. (2) Discharging the cells through the lamps by keeping LS on, CRS*w* adjusted as required, and DS off. (3) Charging and discharging at the same time by running the dynamo with switches DS and LS on, and accumulator switch CRS*w* regulated to pressure of lamps. (4) Running the lamps direct from dynamo by running the dynamo with DS and LS on, and CRS*w* put in the off position. A shunt regulator switch, in this case, can be used to reduce the e.m.f. to the correct lamp voltage. A two-way voltmeter key, VS, makes it possible to read the pressure of the charge or discharge.

In the above figure only single fuses are shown, but double fuses would be used in the dynamo, battery, and lamp circuits, as they afford the best protection.

A *sub-distributing switch* and *fuse-board* contains double-pole switches and fuses. These are fixed at a point where the main cables subdivide, and each switch and fuse controls its own particular part of the circuit only. From thence, in large installations, the mains pass to subfuse-boards, containing double or single-pole fuses; or, in small installations, to single-pole fuse-boards instead, from which the lamp circuits are run; and current through the last fuse should not be greater than 5 amperes at 100 volts, or 3 amperes at 200 volts, but all the conductors on the lamp side must be able to carry this current safely.

In central generating stations different types of switchboards are used, such as the *Flat board*, with and without backs; the *Pillar board*, the *Hinged panel board*, the *Cellular type of board*, the *Multiframe board*, the *Cubicle type of board*, the *Basement* and *Keyboard types*, &c. But a detailed description of these is beyond the scope of this book, and the student must consult an advanced text-book for further information.

To Detect a Leak.—Join up two incandescent lamps (each of the line voltage) in series between the mains; both burn dimly. If an earth wire be led from the nearest water pipe to the junction of the two lamps, and no leak exists, both burn dimly as before; however, should there be a leak, in circuit, one of the lamps burns more brightly than the other one, and the leak will be found in the opposite main to the bright lamp.

CHAPTER XIV.

CONDUCTORS AND CABLES.

Conductors.—Iron wire, though used for telegraph lines, is never used to convey electrical energy for lighting and power purposes, but always copper. The reason of this is that, with alternating currents, the electro-magnetic inertia of iron is too great to permit of the rapid reversals of current which are required, and iron wire has not the same conductivity as copper, but would require to be of a very large sectional area to get the same current to pass as could be easily got to pass through a thin copper conductor. The copper used for electric lighting ought to have 98 per cent. conductivity of that of pure copper. The resistance of copper increases as its temperature rises; it rises about 0·21 per cent. for each degree Fahr., and 0·38 for each degree C.; and owing to this fact, when making laboratory tests, it is either necessary that they be made at the same temperature, or the temperatures at which they are taken be noted and proper corrections made. The opposite of this happens with the filament of an incandescent lamp (a non-metallic body), the hotter it gets the less is its resistance to the passage of currents through it.

Conductors, consisting of one strand only, are called *wires*, with more than one strand they are called *cables*. For wires their diameter is indicated by a number given in a scale known as the *Wire Gauge*, and for cables the number of separate wires is put down as the numerator of a fraction, of which the denominator gives the size of wire on the wire gauge. Example: A $\frac{19}{18}$ cable is one with 19 strands of No. 18 gauge. The area of cross-section of a round wire is expressed in circular mils. A mil $= \frac{1}{1000}$ inch, and the cross-section of a wire of this diameter is taken as the unit of area. The area of any other wire is then expressed by the square of its diameter in mils, and this shows how many unit wires would give the same sectional area of a wire 1 mil diameter. Example: A wire of 20 mils diameter has an area of $20 \times 20 = 400$ circular mils, which shows it is 400 times that of a wire 1 mil diameter. The area in square inches of unit wire is given by the formula—

$$\frac{1}{1000} \times \frac{1}{1000} \times 0{\cdot}7584 = {\cdot}0000007854 \text{ sq. in.}$$

and to find the area of any wire in square inches, we multiply its area in circular mils by this number. Example: By table we find the area of No. 16 is 4,096; hence its area in square inches

$$= 4{,}096 \times {\cdot}0000007854 = 0{\cdot}0032.$$

The usual size of cables are of 3, 7, or 19 strands; while for heavy work 37 and 61 wires are used, being twisted together. Mostly the wires are grouped round a single one as a central core, in rings containing, it may be, 6, 12, 18, and 24 wires, and gives a circular periphery as in any ordinary cable. In the double-concentric armoured street main, the outer ring of wires has the same total area as the main cable. There is also (see p. 160) the three-strand, or clover-leaf, cable, where the wires are in three separate strands all insulated from each other. Wire gauges are the Legal Standard Gauge (L.S.G.), commonly used in this country; the Standard Wire Gauge (S.W.G.), which is still used; the Birmingham Wire Gauge (B.W.G.); and the Brown & Sharpe Gauge (B. & S.), which is standard in America.

Suppose the resistance in ohms at a certain temperature of a piece of copper, 1 inch long and of uniform cross-section of 1 square inch, is known, the resistance of any copper wire of uniform section at the same temperature is got by multiplying this number by the length of wire in inches, and dividing by its area in square inches. Example: Let l = the length of a conductor, a = its cross-section, and ρ = resistance of a piece of wire 1 inch long and 1 square inch cross-section. The resistance of any other size of conductor of the same material is given by formula $R = \rho \frac{l}{a}$. The value of ρ for copper = ·00000067ω, or 67 michroms at 15° C. So that a quarter-mile of copper wire (15,840 inches), having a sectional area of $\frac{1}{100}$ square inch, has a resistance of

$$\frac{\cdot 00000067 \times 15{,}840 \text{ in.}}{\frac{1}{100}} = 1\cdot 061\omega$$

at the same temperature; but, as the resistance of metals rises as they get hotter, so the value of ρ changes with temperature, becoming greater as temperature rises. Suppose we wish to find out what current a given conductor will carry? Perhaps the easiest way is to take a Stubb's wire gauge, bare the insulation off the near end of the wire, carefully gauge it, and note the number of the slot in the gauge which just fits the wire. Then we look up, in a wiring table, for this number of wire, or take the nearest one to it. Suppose it is No. 17, we find, at a current density of 1,000 amperes per square inch, this wire will safely carry 2·46 amperes. Again, if we take a cable containing 19 strands, one of the wires being gauged, it turns out to be No. 16. By table we find 19/16 conductor carries 61·2 amperes at 100 volts; also a single No. 16 wire carries 3·22 amperes. As there are 19 strands, we multiply 322 × 19 = 61·18 amperes, which gives the same result as before. In laying down power or lighting plant, it is necessary to know the loss in watts and volts in a cable. To find the loss in volts, multiply the resistance of the cable by the current flowing; but the distance between the dynamo and motor or lamps is always doubled, to allow for the return conductor; if the lamps are half a mile from the dynamo, then the total length of cable will be one mile.

By the rule of the Institution of Electrical Engineers the maximum currents allowed for conductors to carry are not proportional to the cross-sectional area of the conductor. For small sizes of conductors the permissible currents are greater, and for larger sizes less than the 1,000 amperes per square inch rule will allow. For instance, a No. 17 conductor carries, by the old rule (1,000 amperes per square inch), 2·46 amperes. The absolute maximum current allowable by the I.E.E. rule is 5·45 amperes (see "Electric Rules and Tables," by Maycock). It is only permissible, by this rule, for small conductors, such as Nos. 22 to 15, to work at double the current density allowed by the old 1,000 amperes per square inch rule, and the fire insurance companies, in the event of a change over, say from 100 volts to 50 volts, will only allow the same conductors to carry half the current at the lower voltage and supply half the power from what they did at the higher voltage. If it be necessary to supply the same power* as before, then a fresh conductor must be substituted of a larger sectional area. A conductor, say No. 20, will safely carry 1 kw. of energy at 1,000 volts and yet fuse with the same power at 15 volts. The reason for this is owing to the heat produced, which varies with the square of the current.

Refer back to p. 22 for the heating effects of a current, where you will find the formula given—

$$\text{Calories} = \text{C}^2 \times \text{T} \times \text{R} \times {\cdot}24.$$

The resistance of No. 20 conductor is 0·023 ohm per yard, and suppose we send a current through that length for one minute (60 seconds). The conductor must carry, at 1,000 volts, 1 ampere, for

$$1 \times 1{,}000 \text{ volts} = 1{,}000 \text{ w.} = 1 \text{ kw.}$$

Then, by the above formula—

$$1^2 \times 60 \times {\cdot}023 \times {\cdot}24 = {\cdot}33 \text{ calorie},$$

which is the heat developed, and the conductor can safely stand this amount without fusing.

Again, to convey 1 kw. at 15 volts, the conductor must carry 67 amperes, for

$$67 \times 15 \text{ volts} = 1{,}005 \text{ w.} = 1 \text{ kw fully.}$$

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* To carry, at a lower voltage, the same power means a corresponding increase in current.

Then, again,

$$67^2 \times 60 \times {\cdot}023 \times {\cdot}24 = 1{,}486 \text{ calories},$$

and this great amount of heat developed fuses the conductor.

Exercise.—To find the loss in watts in, say, a 7/15 cable, 1 mile long, with 30 amperes (1,000 amperes per square inch density), resistance of 1 mile of this cable $= 1{\cdot}5\omega$ (ohms),

then $$1{\cdot}5 \times 30 = 45 \text{ volts lost.}$$

As a rule, there is a loss of, approximately, 2·4 volts per 100 yards of single conductor where the current density = 1,000 amperes per square inch section of copper.

It is always necessary in estimating the size of dynamo required to drive a motor or light lamps to add to the actual watts required at the terminals those lost in the cables, and the dynamo must be able to give at its terminals an e.m.f. = the volts lost in the cables, plus the volts required at lamp or motor terminals. For electric-light work, it is usual to employ vulcanised rubber-covered conductors, the insulation resistances of which for main and branch conductors are 600 megohms per mile. For branch wires a single conductor of No. 22, 20, 18, or 16 B.W.G. is used; but insurance companies insist that a smaller single wire than No. 20 or larger than No. 18 be not employed; if a larger size of wire is required, then 3/20 or 3/22 cable should be used. Cables are made up of a number of wires, consisting of 3, 7, 19, 37, or 61 strands, of No. 22, 18, 16 or 14 B.W.G., according to the diameter of the conductor required and the number of lamps run.

Casing for Conductors.—Inside buildings the conductors are led along in *wood casing* (Fig. 146), which is composed of two grooves and a central fillet, the sizes depending on the gauge of wires they hold. There is a cover put on by screws, and the casing is screwed to the wall by screws passing through the central fillet. In joining the lengths of casing together, the ends are generally mitred. Fig. 146 shows how a casing is joined when it is necessary to make a T joint, as when the conductor drops down to a switch. The use of wood is being discarded, especially in America, owing to the fact that it contracts damp and moisture, and this passes over from the + wire to the (–) wire, and the wood is apt to rot. In old buildings, where everything is dry, wood casing does very well, but not in new buildings, and is now being replaced by *pipe work*. This is fire-proof, and waterproof to external moisture, but heavier to work. When running conductors in casing, the rule for placing the conductors is: Leads left, returns right, when running vertically; and leads low, returns raised, when running horizontally. The "lead" wire runs from the + terminal to the lamps, and the "return" wire passes back to the (–) terminal. This arrangement always holds good in a continuous-current system. With an alternating current neither conductor can be called + or –, as the polarity is constantly changing.

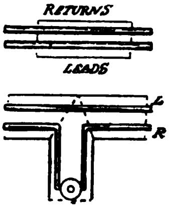

Fig. 146.

The *simplex steel conduit system* is used frequently, and consists of a light steel tube, enamelled inside and outside with special "stove enamel," or else galvanised. Two lengths of tube fit inside a bored-out coupling and are socketed home against a shoulder, forming a tight joint. In another form there is no butt-joint, but the tube is brazed. Special screwed conductors are also used. Pipe work is mostly put under the surface, between floors and ceilings. Draw-in boxes are always required, as the conductors cannot be pulled round two or three bends, thus small metallic boxes with removable lids are fixed, so that the conductors can be "eased" round about corners, &c., and can all be fixed up in a new house before the plastering is done. The metal pipes are conductors, so they must be made mechanically and electrically continuous, and be connected to earth in one or two places by a copper wire joined at its far end to a water-pipe. As it is possible for a person to receive a shock by touching the pipe, should a conductor get into electrical contact with it, to prevent this accident the *insulated conduit system* has been devised, and is used by the Conduit and Insulation Co., Ltd. It consists of a closed steel tube, lined throughout with paper, impregnated with a high-resistance insulating compound. All pipe-fittings, bends, tee-pieces, and draw-in boxes are lined with this material and ordinary screwed joints are used.

The *Fowler-Waring Co.'s lead-covered cable* is of the "concentric" variety: the + stranded conductors are insulated from, and surrounded by, the stranded (–) conductors, which are in metallic connection with the lead sheath. They are run along without pipe or wood casings. The two conductors (both insulated from each other) run inside the same lead pipe.

Messrs Mavor & Coulson (of Glasgow) make a *concentric system of wiring*. The main cables are lead-sheathed, often armoured; these pass from the switch-board to distributing boxes of cast iron or brass, fitted with fuses, or fuses and switches, and which are made perfectly water-tight. Concentric branch cables radiate from these, all being of uniform section, ·005 square inch, $\frac{7}{21\frac{1}{2}}$ unarmoured, enclosed in lead (this size will carry 5 amperes). A joint is never made except inside a jointing box. The centre stranded cable is soldered to a brass contact, insulated from the bottom of the box, and the other conductor (which surrounds the inner one) with its lead sheath terminates in a jointing pocket in the junction box, which is filled up with solder. The central conductor is thus enclosed by the outer and the metal sheath, from which it is insulated at all points.

Flexible conductors for pendants terminate at both ends in a screwed brass nipple, with insulating plugs and central contacts. The top nipple of the pendant is screwed into the junction box so that the central contact makes electrical connection with the central brass contact in the jointing box, and the outers make electrical connection with the junction itself. Flexible conductors have a silk covering outside. By using only one size of conductor to the lamps, and only one size of junction box, one size of branch fuse only is required.

Lamp-holders contain only a single central contact plunger, the top of which makes contact with the insulated central contact (joining with the + conductor) when screwed on. The lamps have one end of the filament joined to the central contact plate, and the other to the brass collar. Current passes through the central conductor to the junction, through the brass button and central pendant to the single-contact plunger in the lamp-holder, round the filament, and then returns by the brass collar, holder, and outer conductor to the junction box, and from thence, by the (–) conductor, and lead sheathing, back to the dynamo. The makers claim many advantages for this system, among them being that no wood casing is required. The cables pass through buildings like flexible gas-pipes, and can be embedded in the plaster of the walls, an infallible safeguard from fire. No stray currents will pass to affect the compasses of a ship. Should the insulation get punctured, the fault immediately develops a "dead short," and the main fuse blows before any damage is done. As the outer conductor is at earth potential, there is no risk of shock, &c.

For Wiring the Interior of Houses, vulcanised rubber wires are used. Pure rubber is put next the wire, then two layers of vulcanised rubber, a layer of rubber-coated tape, and outside hemp braid. The tape and braid are more for mechanical protection than insulation. The conductors are always tinned. The minimum insulation resistance for low-tension cables at 100 volts is 300 megohms per mile after twenty-four hours' immersion, and one minute's electrification. In high-tension cables under the same conditions, at 2,000 volts it is at least 4,000 megohms per mile. For movable fittings, such as a table lamp, pendant, &c., attached to a wall plug, twin flexible conductors are used. The two insulated conductors are laid together, twisted spirally, and covered outside with cotton or silk. In damp places a tarred hemp covering is put on in addition. In installations it is best to arrange so that the drop in pressure does not exceed 1½ volt between the main distributing-board and the farthest lamp when all the lamps are lighted on a 100-volt circuit.

Jointing.—Resin is always used as a flux, the insulation covering is cut away for a short distance from either ends of the wires to be joined together, or the rubber would melt and flow over the joint. After soldering, rub rubber solution over the cable for about 2 inches round the joint. Pure Para rubber strip is then lapped together round the joint, and the lapping must start and end on the vulcanised rubber. Use three layers, and put solution between each. Next to this put on two layers of prepared double waterproof tape over the joint, and tape and braid the conductor as well.

The Single-wire System (Fig. 147).—There is one main only with branches. It was used on board ship, the metal skin of the ship forming the earth or return wire. As there was danger of faults arising,* this method has been abandoned on board ship, and the Board of Trade no longer permits its use for domestic lighting.

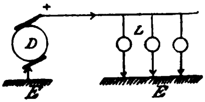

Fig. 147.

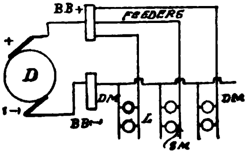

Fig. 148.

In central station work main conductors are divided into three classes—feeders, distributers, and service mains.

Two-wire System.—See p. 166.

Feeders.—Current is led from the switch-board bus-bars in the generating station to the area of supply, not by one, but by several conductors; these are called "feeders," and their junctions with the mains are called "feeding points," and the voltage at these parts must be kept constant by regulation at the generating station. These points are placed at different distances apart according to requirements (Fig. 148).

Fig. 149.

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* Such as deviation of the compass needle.

The **distributing mains** DM form the junction between the feeders and the service mains. They get the supply of current from the feeders, and distribute it over a given area of the town, and give it out at fixed places to the service mains. They are arranged in a network. Trunk main feeders may be No. 91/9 S.W.G.; subsidiary ones No. 61/11 S.W.G.; distributers No. 61/11 S.W.G. (Fig. 148).

Service mains are the conductors through which current passes to any consumer's house for his use. They are only a few yards in length, as service boxes are generally put down about every 25 yards or so along the distributers. They are mostly insulated with vulcanised rubber, and sometimes armoured. The house end of one of these connects to the consumer's wiring in a junction box with fuses (Fig. 148).

When cables are laid beneath the roadways or in the earth, different systems are adopted.

(1) *Conduit System.*—The cables are laid in cast-iron pipes or earthenware pipes. Doulton stoneware casing is shown (Fig. 149) with a separate way for each cable to pass through.

(2) *Callender's "Solid" system* consists in laying the cables in wooden or cast-iron troughs, and surrounding them with Trinidad bitumen; but the wood is boiled in Stockholm tar free from creosote. The cover consists of wood or tiles (Fig. 150). The cables rest on wooden bridges at intervals. Sometimes feeders are supported on solid insulators at intervals inside the casing, and air forms the insulation. An insulator is fixed, say, at every 6 feet, and the rectangular copper conductor is laid on edge in grooves (Fig. 151). Cast-iron junction boxes are used at all the places where the cables join each

Fig. 150.

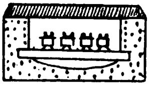

Fig. 151.

other or give off branches, the junctions being made inside these boxes.

For high-pressure, continuous, and single-phase alternating current concentric cable is used. There are two conductors, one of which completely surrounds the other at all points (Fig. 152). These give no external magnetic field. Triple concentric cables consist of three conductors, the third being placed round the outer conductor of a concentric cable. Sometimes, instead of this arrangement, the three cables are all insulated from each other, and laid up in a single lead sheath (Fig. 153). They may be circular or of a triangular section, and this last is called a "clover-leaf" cable. These are used for three-phase working.

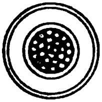
Fig. 152.

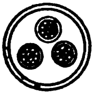
Fig. 153.

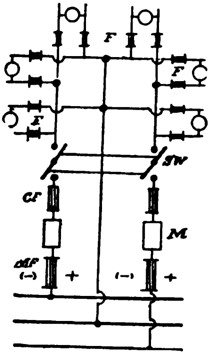

Fig. 154.

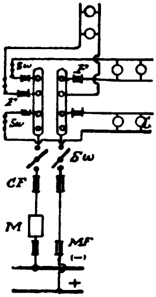

Fig. 155.

Arrangement of Circuits for Distribution.—In the wiring of buildings two methods of arranging the conductors are used:—

(1) *The "Tree" system* (Fig. 154), which is not much used

now, owing to the unequal distribution of light, the multiplicity of joints, and fuses scattered all over the building. A pair of main cables start from the street mains, pass through the company's main fuse MF and meter M, the customer's main fuse CF and switch s*w*, then ascend vertically. At each floor branch mains are tapped off, which run horizontally between the floor and ceiling, and from these again branches pass to the lamps, these being larger or smaller according to the number of lamps they supply. Thus the whole current passes along a single pair of mains, and wherever a pair of conductors join a larger pair a fuse, F, is inserted at the junction.

It will be seen that here half the circuits are joined up between the + conductor and the neutral wire, and the other half between the (–) conductor and the neutral or middle wire.

(2) *The "Distributing-Board" system* (Figs. 155, 156) is used in all good modern installations. The main cables, after leaving the street mains and company's fuse, MF, pass through the meter M, consumer's fuse CF, and switch s*w*, to a distributing-board, MB, mounted on a slate base, on which are grouped the main fuses. From them branch cables run through DP, fuses F and SP, switches s*w*, to the lamps in a small installation, or through DP fuses only, to subsidiary distributing-boards on the various floors in the house in a large installation, and from these last the lamp circuits run direct through DP fuses and SP switches. With two wires, one distributing-board generally suffices; but on the three-wire system subdistributing-boards are used.

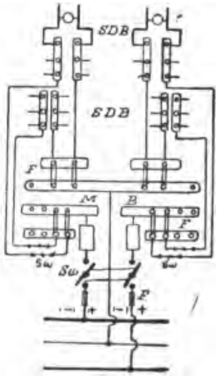

Fig. 156.

Fig. 156 shows a three-wire distribution, MB being the main board, SDB being the subdistribution-boards from which the lamp circuits are supplied, some being joined up on the + side and some on the (–) side of the system, so that the lamp circuits are really two-wire circuits, the middle wire having no connection with them. The number of lamps on each circuit are so arranged that the current per circuit does not exceed a certain limit. On a 100-volt circuit, this limit is about 5 amperes, for which a cable of $\frac{7}{21\frac{1}{2}}$ is used. When the current has been reduced to 2 amperes, then a $\frac{3}{32}$ cable or a single No. 18 can be used (the smallest size used). With the above system an arrangement of conductors can be used, called the "*looping-in*" *system*, by which joints can be done away with. More wire is used, but labour is saved, and higher insulation resistance attained.

In ordinary wiring, joints must be made at the junction of the lamp circuit with the mains. In Fig. 157 the lamp and switch are shown wired without any joints by the *looping-in method*, the joints being made under the clamping screws of the terminals in the fittings. The lead and return wires at J^1 J^2 are all in one piece, being looped and stripped of their insulation in order to make contact under the clamping screws.

Sometimes it is arranged that the whole or part of an installation can be supplied with current from two different sources, so that in case of the breakdown from one source, current can still be had from the other one, and this is accomplished by bringing the lamp terminals to a double-pole change-over switch, which can be made to make contact with either pair of bus-bars on switch-board, each pair receiving current from a different source.

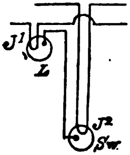

Fig. 157.

Exercise.—A dynamo with 200 volts pressure at the terminals supplies 15,000 watts to a house 250 yards off. What must be the cross-section of the copper conductors so that not more than 5 per cent. of the power is wasted in them? Resistance of 1 cubic inch of copper is 0·66 michrom; 5 per cent. of 15,000 watts wasted in the conductors is—

$$\frac{15{,}000 \times 5}{100} = 750 \text{ watts.}$$

Current sent to house is—

$$\frac{\text{W}}{\text{E}} = \frac{15{,}000}{200} = 75 \text{ amperes,}$$

which is the current in the conductors. R = their resistance; then the watts wasted in them $= \text{C}^2\text{R} = 75^2 \times \text{R} = 750$. Hence—

$$\text{R} = \frac{750}{75 \times 75} = 0{\cdot}133\omega \text{ (ohm).}$$

Total length of conductors $2 \times 250 \times 36$ inches. Hence—

$$\text{R} = \frac{2 \times 250 \times 36 \times 0{\cdot}66}{100{,}000{,}000 \times a} = 0{\cdot}133.$$

Here a is the required area of cross-section. Hence—

$$a = \frac{500 \times 36 \times 66}{133 \times 100{,}000} = 0{\cdot}0893 \text{ sq. in.}$$

By table we find that $\frac{19}{14}$ cable containing 0·0973 square inch is the nearest.

Tests for Continuity and Insulation Resistance.—After the wiring of a house has been finished we test for *continuity* first, by means of a detector-galvanometer, or an electric bell and a few dry cells. Join up to the ends of the mains, the switches being closed and fuses inserted at the distributing-boards. The bell is joined up at each lamp in turn, and if the wiring is correct the bell rings at every point when current is turned on. A detector-galvanometer would do instead of the bell, but the latter can be heard when the former must be seen; so two persons are required to do this last test.

Insulation tests can be performed with Evershed's ohmmeter and generator set. The former is direct reading, and shows whether the insulation is good or bad under tests in megohms. The latter is a small hand dynamo driven up to speed, and will give current from 100 to 1,500 volts pressure (Fig. 158).

First.—To find ***the insulation resistance of the whole wiring between both poles and earth*** before the fittings are fixed. Strip off about 2 inches of insulation from the ends of each main; scrape them, and join them up to the ohmmeter terminal marked "line." To the terminal marked "earth" join a piece of bare wire. To the end of the earth wire is joined a good earth, such as a water-main or pipe. The two generator terminals are joined to the ohmmeter terminals. Place the two, the ohmmeter and generator, about 18 inches apart, to prevent errors. Level them with a spirit-level, and adjust the screws. The generator-handle is turned about 60 revolutions per minute, and the insulation resistance under test read off on the ohmmeter dial.

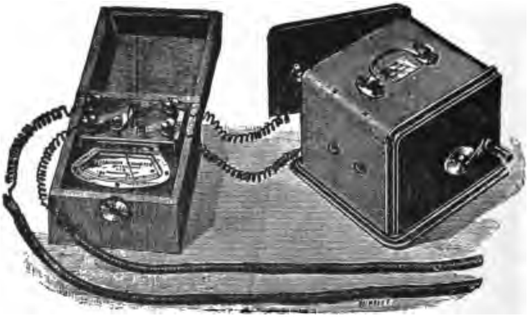

Fig. 158.

If the resistance be over 1 megohm (say this is the fixed standard) all is right; but if below it, there is a fault, and this must be localised. For this test it is necessary that all switches are on and all fuses in, as the wiring is only done to lamp points. If the fittings are fixed all the lamps must be put in. Fig. 159 gives a diagrammatic representation of the arrangement of the apparatus. C is the cable, R is a resistance, G is the galvanometer or ohmmeter, B is the battery or generator, EW earth wires, and E earth. Or, again, instead of earthing the battery and the cable insulation, the (–) end of the battery could be joined direct to the cable insulation, and the test taken in this way; or it might be done in both ways if thought desirable.

Second.—*To measure insulation resistance between poles*, remove the earth wire from the ohmmeter terminal, and with an insulated wire join this terminal to one pole of the wiring, the other pole of the wiring being already joined to the ohmmeter terminal. If the fittings are fixed, remove the lamps, put on the switches, and leave all fuses in. If the wiring is taken to points, the conductors at the lamp points must be separated, and all switches and fuse points closed. If possible, always test before the fittings are fixed, as well as afterwards, as the final test shows if low insulation is due to the fittings or the wiring. The test should be made from the main fuses, or, if these be not fixed up, from the position they will occupy. The nature of the fittings used, and the dryness or dampness of the house, affect the results obtained.

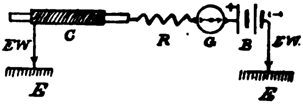

Fig. 159.

In Fig. 160 cc are the cables + and (–), R the resistance in circuit, G the galvanometer or ohmmeter, B the battery or generator, these being shown diagrammatically. A good "earth" is formed by putting a copper plate into a hole, sufficiently deep, amongst damp earth, and putting layers of crushed coke both above and below the plate, then filling up the hole with earth. A wire attached to the plate forms the earth wire.

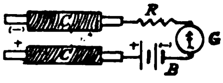

Fig. 160.

The rule given by the Phœnix Fire Office for the proper insulation resistance of electric-light circuits is: For installations working at 200 volts or under, divide 12·5 megohms by the number of lights, and the result is the minimum insulation resistance for continuous currents. For alternating currents this resistance should be doubled. Example: suppose there are 25 lights, then—

$$\frac{12{\cdot}5}{25} = 0{\cdot}5 \text{ megohm, but } 1 \text{ meg.} = 1{,}000{,}000\omega.$$

$$\therefore\quad 1{,}000{,}000 \times 0{\cdot}5 = 500{,}000\omega.$$

Professor Jamieson's rule is—

$$\text{Resistance from earth} = 100{,}000 \times \frac{\text{e.m.f.}}{\text{No. of lamps}}.$$

It is best to test at double the working pressure; if the installation is run at 100 volts, test at 200 volts. After the installation has been in use for two or three weeks, take a second insulation test, and if it be then lower, the cause must be discovered. A new house which is always damp will not show so high an insulation resistance as a dry one, though both the workmanship and materials are good, but it should rise as the house gets drier.

Pilot wires are wires which run from the feeding points on two wire feeders to voltmeters in the generating station, and on these last are recorded the voltage at the feeding points, and the pressure must be kept constant at each feeding point.

Note.—Whenever a conductor bridges over another one as in Fig. 154, this shows that there is no electrical connection between the two, and so no current can pass from one to the other.

The Two-wire System.—In this, the lamps are joined up to smaller conductors which join the two main conductors, all the conductors are insulated, and are at one or other of two pressures from earth potential. The current flows, from the generator, by one conductor and returns by the other one, after passing through the lamps. This system is used in private installations, and for ship lighting, &c.

CHAPTER XV.

ELECTRICAL ENERGY METERS—SPECIFICATIONS.

Electrical Energy Meters.—These instruments serve the same purpose as gas-meters do in a gas supply; they register the amount of current supplied from the generating station to each consumer and used up in his lamps. The meter is put in the consumer's house, and he has to pay according to the number of B.T.U.'s of electricity consumed and registered thereon.

Meters are divided into two main classes: (1) Quantity, coulomb, or ampere-hour meters; (2) Energy, or watt-hour meters, and the counting dials are generally read in B.T.U.'s. They are again further divided into three classes: (*a*) *Chemical* or electrolytic meters; (*b*) *Motor-meters*; (*c*) *Clock-meters*.

(*a*) The first depend for their action on the chemical effect of the current, and so can only be used on direct-current circuits, and the amount of electro-chemical action is proportional to the quantity of electricity that has passed through the meter. Edison's meter was the first of this type; it was a coulomb-meter, and consisted of a balanced beam with copper plates suspended—one at each end—in a copper sulphate solution. A current, passing from one plate to the other, dissolved the former and deposited copper on the latter till it got sufficiently heavy to tip the beam. This also registered a unit on a counting mechanism and reversed the current, so that the heavier plate was dissolved, and the lighter one had

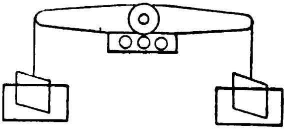

Fig. 161.

copper deposited on it, and so on continually. It was joined up as a shunt to the main circuit, so that only a small current passed through (Fig. 161). In the improved form of meter the current flows one way only; the plates used are amalgamated. They must be taken out, weighed, and fresh plates put in once a month. The variation in the proportion of current flowing through with the temperature is eliminated by putting a copper resistance in series with the liquid, of such a value that its increase of resistance, due to increased temperature, equals the decrease in resistance of the liquid, due to increased temperature. An incandescent lamp burns in the meter to prevent the solution from freezing (Fig. 162). This meter has been much used in America with good results.

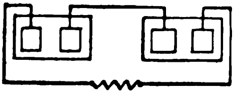

Fig. 162.

(*b*) *Motor-meters* form a very large class of meters. In these, the counting mechanism is acted on by the revolutions of a motor through which the whole, or a part of the current only, passes. They have, as yet, the preference, and form the largest class at present in use. They require little attention: there is no clockwork gear to wind up, no plates to be weighed, and no cell to be periodically changed. Nearly all these meters are direct-reading, or the dial-reading must be multiplied by a constant, as in meters which carry large currents. Examples: Schallenberger, Elihu Thomson, Ferranti, Hookham (direct and alternating).

Schallenberger's Motor-meter for Alternating Currents (Fig. 163).—It is made by the Westinghouse Co., of Pittsburg, and is constructed up to 200 amperes. The moving part consists of an aluminium disc, A/D, fixed upon a pivoted vertical spindle. The lower end of the spindle carries four aluminium vanes, the use of which is to retard the motion, by means of the friction set up between the air and the fan attached to the shaft. The torque varies approximately as the square of the current and

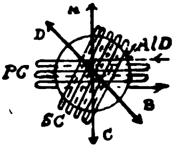

Fig. 163.

the friction as the square of the speed; then, when the driving force and retarding force balance each other, the speed varies directly as the current. Surrounding the disc is the primary coil PC. Inside this, at an angle of 45°, is the secondary coil SC, which is short-circuited upon itself. Current in the main coil PC induces a secondary current in SC which lags behind the primary current. Suppose the primary field set up is in the direction of the arrow A, then the arrow B gives the secondary or induced field. On reversal of current the field in PC is opposite, or in direction of the arrow C, and the induced field in the direction of the arrow D. Thus we get a rotating field set up in the secondary coil, and this causes the disc to rotate in a clockwise direction, and the dial pointers to move across the dials. The meter records ampere-hours, so that it is a coulomb meter.

Ferranti meter is a direct-current current-meter. The principle of its action depends on the fact that, when a current is led through a fluid such as mercury, placed in a magnetic field, the mercury tends to move in a direction perpendicular to the direction of the current and to that of the magnetic field.

Elihu Thomson watt-hour meter is an energy meter, and can be used with both continuous and alternating currents, as it contains no iron. The field consists of two coils of thick wire which carry the main current, one on each side of the armature A. The armature A consists of a hollow frame, wound with fine wire coils, and to one end is fixed a silver commutator C, on which two light brushes, with silver contact pieces, rub. The armature is fixed as a shunt between the mains, and is in series with a high non-inductive resistance NR, fixed on the back of the meter frames, forming the pressure coil. In order to cause the speed to vary directly as the power, a copper disc (not shown in Fig. 164) is fixed on the armature spindle and rotated in a magnetic field set up between the poles of two permanent magnets. The torque is

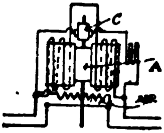

Fig. 164.

proportional to the current multiplied by the voltage, and to prevent the speed from increasing too rapidly, a retarding force is set up by the copper disc arrangement. Current, generated in the disc, is proportional to the speed, and so the retardation of the armature is proportional to the current multiplied by the field, which is also proportional to the speed. Hence, the resultant speed of the armature is proportional to the power. This meter starts with a very small current, such as half an ampere for a 50-ampere capacity meter.

(*c*) *Clock-meters* (Fig. 165) are applicable for direct and alternating currents, and are used as coulomb, or energy meters. This meter consists of two similar clocks, C_1, C_2, both gearing on a common dial. C_1 has an ordinary pendulum oscillating regularly, C_2 has a permanent magnet or shunt coil, SC, on the end of the pendulum, which oscillates inside the main coil M. While the clocks work synchronously, the indicating gear does not rotate, and the pointers do not move; but if any difference of speed arises the pointers move, and the amount recorded on the dials = the difference in speed between the two clocks. When current passes through M, it quickens the action of C_2 over C_1, in proportion as the current is large or small, and the difference is recorded by the pointers, and the amount registered is directly proportional to the current which has passed through the meter. A constant is used. The meter runs for three months at one wind.

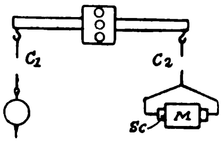

Fig. 165.

This meter has been much improved lately and made self-winding; both pendulums carry a fine wire coil, one being accelerated and the other retarded by the current, and it is applicable both to continuous and alternating currents. Meters are all read like gas-meters. Lord Kelvin's meter consists of a weight-driven clock, which automatically breaks the circuit when it requires winding, an ampere balance, and an integrating cam. The clock is put on one side, and is automatically wound up by current every thirty seconds. On the other side is an apparatus to measure the current strength, which consists of a long soft bar of iron, wound with 1,000 turns of fine wire (Fig. 166). A very small current keeps constantly passing through the coil, and this magnetises the iron to saturation, and it is pulled down against the force of bearing springs by an amount proportional to the current strength in the main solenoid. The electro-magnet, having a fixed value of 25 amperes, sucks down the core into its interior. Above the core is placed a rod which, when the core is lowered into the solenoid, is allowed by the movement of a rod attached to the clockwork mechanism to fall downwards in proportion to the space between it and the solenoid core, and in so doing it moves the train of dial wheels and measures the current. When the rod has fallen the clock winds it up again, ready for it to fall down and measure the current as before. This instrument is put in circuit as a shunt between the mains.

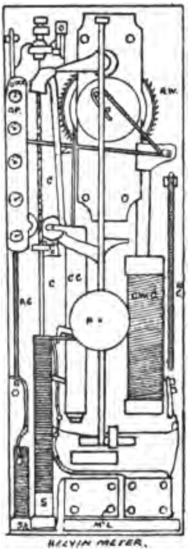

Fig. 166.

Meters are very often supplied by the Electric Lighting Company free of charge; but sometimes a small fee is charged of 2s. 6d. per quarter. For electric radiators, heating, and power purposes, charges are often made at half the ordinary lighting rate. Meters are all read like gas-meters: the dials run from right to left in reading, thus single units, tens of units, hundreds of units, &c. When the pointer stands between two figures the smaller one is taken. Some meters have a constant or multiplying number, and the Electrical Company supply the value of the constant.

The Wright demand indicator (Fig. 167) consists of a U-shaped glass tube, GT, and a gauge tube on the right-hand leg of the U-tube near the bulb J. A resistance coil, R, is wound on an air-bulb, AB, and current passes through this to the consumer. The U-tube is filled with a dark liquid. When AB gets heated by the current, this liquid rises and flows over the junction J of the two tubes, and partly fills the gauge tube T, which is closed at the foot. The scale on it reads from below upwards. The height of the column is a measure of the maximum current that has ever been taken. To reset the instrument, it is tilted upwards and outwards, and the bulb is heated till the liquid column joins the trapped fluid, when the whole then runs back into the tube, and refills it ready for use again.

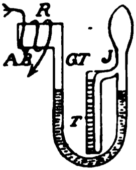

Fig. 167.

For the sale of current to consumers there are three methods of charging :—

1. *The Flat-rate System*, where a fixed price per unit is paid regardless of the amount of energy consumed or the nature of the demand, whether for lighting or power purposes.

2. *The Flat-rate System with a Scale of Discounts.*—There is so much per cent. allowed on the quantity consumed, which discount increases by a gradual scale to a fixed maximum charge.

3. *The Maximum Demand System.*—Here two instruments are used—a meter to register the amount of energy consumed and a demand indicator to record the maximum demand, or the largest quantity of electrical energy in actual use at some particular time during a quarter-year. Both meters are placed in the consumer's premises. The rate of charge might be 7d. per unit up to an equivalent of 100 hours' use during the quarter of maximum demand, and 3d. per unit for all consumption during the quarter above 100 hours' use.

Exercise.—A consumer has forty-three 16-c.p. lamps, each taking, say, 4 w, then

$$4 \times 16 \times 43 = 2{,}752 \text{ watts,}$$

and it is found that the meter registers a consumption of energy for the quarter-year of 180 units; and the demand indicator shows that the highest number of lamps in use at some particular time during the quarter required 900 electrical units; then the maximum demand would be fixed at 900 watts, and the charge made as follows:—

90 units $\frac{900\text{w.} \times 100\text{ hr.}}{1,000} = 90$ units.

	£	s.	d.
at 7d. per unit - - -	=2	12	6
90 units (being $180 - 90 = 90$) at 3d. -	=1	2	6
	3	15	0

This averages 5d. per unit nearly.

This system, now falling into disuse, is adopted as it encourages consumers to use a large number of their lamps for many hours per day.

Exercises.—12 watts are supplied for 10 hours at 8d. per B.T.U.

$$\frac{12 \times 10}{1,000} = \frac{120 \times 8}{1,000} = 0{\cdot}960\text{d.} = \text{about } 1\text{d.}$$

If 10 amperes at 100 volts are consumed, how many watts would this be in 10 hours at 6d. per B.T.U.?

$$\text{C} \times \text{E} = \text{W}, \; 10 \times 100 = 1,000$$

$$\frac{1,000 \times 10}{1,000} = 10 \times 6 = 60\text{d.} = 5\text{s.}$$

Specifications.—We give two examples of the methods of making out specifications: (*a*) How to calculate the number of lights required and the sizes of conductors to be used in the wiring of a hall; (*b*) How to arrange a 40-light installation for a two-story house, and, from these, we trust the student will learn how specifications for individual installations are calculated.

(*a*) For *small hall*, or *class-room* (the dynamo and engine being placed in a building just outside), we want to find out the number of lamps required, the size of conductors, also the horse-power of dynamo and engine required. The length of the class-room is 26 ft. long, 25 ft. 6 in. wide, then 26 ft. × 25 ft. 6 in. = 663 sq. ft. area. For good illumination, allow one 16-c.p.

lamp for every 50 sq. ft. of surface, $\frac{663}{50} = 13{\cdot}2$, say 14 lamps, hung from ceiling by flexible cords, three lamps in each holder. There are four holders, three lamps in each; then $3 \times 4 = 12$ lamps, hung from ceiling, and two more, one on each side behind the lecture table, on brackets coming out from wall. Now, $12 + 2 = 14$ lamps in all. Arrange the wiring on the tree system in this case, though in practice it might be done on the distributing-board system.

Each lamp, we find by tables, takes 65 watts, so 14 lamps take $14 \times 65 = 910$ watts, so that this amount must be carried for lighting purposes only. For—

No. 1 branch with its 3 lamps takes $65 \times 3 = 195$ w.
„ 2 „ „ „ „ $65 \times 3 = 195$ w.
„ 3 „ „ 4 „ $65 \times 4 = 260$ w.
„ 4 „ „ „ „ $65 \times 4 = 260$ w.
910 w.

We fix upon the dynamo to give a voltage of 105 volts at its terminals. To find the current required, $\frac{\text{W}}{\text{E}} = \text{C} = \frac{910}{105} = 9$ amperes.

No. 1 branch must carry $\frac{\text{W}}{\text{E}} = \text{C} = \frac{195}{105} = 1{\cdot}8$ amp.
„ 2 „ „ „ $\frac{195}{105} = 1{\cdot}8$ „
„ 3 „ „ „ $\frac{260}{105} = 2{\cdot}4$ „
„ 4 „ „ „ $\frac{260}{105} = 2{\cdot}4$ „
8·4 (say 9 amps.)

We find, by tables, No. 7/18 carries 12·8 amperes safely: use this size of conductor for the mains, lead and return, its resistance = ·000645ω per foot. For the branches, No. 16 carries three amperes safely; use this size of conductor for all the branches; its resistance = ·002536ω per foot.

Suppose, by measurement, we find that the conductors must be of the following lengths:—

The main one is 50 ft. long; double this for return, then - - - - - $50 \times 2 = 100$ ft.
No. 1 branch is 12 ft. long; double this for return, then - - - - - $12 \times 2 =$ 24 ft.
No. 2 branch is 12 ft. long; double this for return, then - - - - - $12 \times 2 =$ 24 ft.
No. 3 branch is 22 ft. long; double this for return, then - - - - - $22 \times 2 =$ 44 ft.
No. 4 branch is 22 ft. long; double this for return, then - - - - - $22 \times 2 =$ 44 ft.
236 ft.

The mains have a resistance of ·000645ω per ft.

Then the resistance of 100 ft. $= {\cdot}000645 \times 100 = 0{\cdot}0645\omega$
The resistance of all the branches in parallel $= 0{\cdot}0197\omega$
Total, $0{\cdot}0842\omega$

$$\text{for } \frac{1}{\frac{1}{r1}+\frac{1}{r2}+\frac{1}{r3}+\frac{1}{r4}} = \frac{1}{\frac{1}{\cdot0608}+\frac{1}{\cdot0608}+\frac{1}{\cdot1115}+\frac{1}{\cdot1115}}$$

$$= \frac{1}{50{\cdot}72} = 0{\cdot}0197\omega$$

Watts lost in lighting the lamps we found as - - 910
Watts lost in the conductors $= \text{C}^2 \times \text{R} = \text{W} = 9^2 \times {\cdot}0842 =$ 6·82
Total, 916·82

To find the current that must be generated

$$\frac{\text{W}}{\text{E}} = \text{C} = \frac{916{\cdot}8}{105} = 8{\cdot}7, \text{ say 9 amperes at 105 volts.}$$

Size of dynamo required—

$$\text{E.H.P.} = \frac{\text{E} \times \text{C}}{746} = \frac{105 \times 9}{746} = 1{\cdot}2, \text{ say } 1\tfrac{1}{4} \text{ E.H.P.}$$

Assume the dynamo's output to be 917 watts, with an efficiency of, say, 90 per cent. Then the engine B.H.P. required is

$$\frac{\text{W} \times 100}{\text{E.H.P.} \times 90} = \frac{917 \times 100}{746 \times 90} = 1{\cdot}36 \text{ or } 1\tfrac{1}{2} \text{ B.H.P.}$$

A ½ N.H.P. gas engine of good make will give fully 1½ B.H.P., or about 2 I.H.P., and be suitable.

Fuse wires required: Main ones (double-pole), No. 18 S.W.G. (lead), carries safely 14·5 amperes. Use this size. For the branch wires use the same size (double-pole). For the ceiling roses use No. 24 S.W.G. (lead): it carries safely 4·4 amperes (single pole).

(*b*) We arrange a *forty-light installation for a two-story house* and light it from the mains, at 100 volts, by incandescent lamps.

On the ground floor we have :—

In kitchen - -	2	lamps, forming	2	lighting points.
Scullery, - -	1	,,	1	,,
Servants' bed-room, -	1	,,	1	,,
Lobby - - -	2	,,	2	,,
Smoke-room - -	2	,,	2	,,
Drawing-room - -	8	,,	4	,,
Dining-room - -	8	,,	4	,,
	24	,,	16	,,

On floor upstairs :—

Lobby - - -	2	lamps, forming	2	lighting points.
Bath-room - -	1	,,	1	,,
Boudoir - - -	4	,,	2	,,
No. 1 Bed-room - -	2	,,	2	,,
,, 1 Dressing-room -	1	,,	1	,,
,, 2 Bed-room - -	2	,,	2	,,
,, 2 Dressing-room -	1	,,	1	,,
,, 3 Bed-room - -	2	,,	2	,,
,, 4 Bed-room - -	1	,,	1	,,
	16	,,	14	,,

The lamps can all be supplied from one distributing-board in the lobby (which supplies the ground floor and upstairs). Five circuits run from this board.

No. 1 circuit supplies:—

Kitchen	2 lamps.
Scullery	1 „
Servants' bed-room	1 „
Lobby	2 „
Smoke-room	2 „
	8 lamps.

No. 2 circuit supplies:—

Dining-room	3 lamps.
Drawing-room	5 „
	8 lamps.

No. 3 circuit supplies:—

Dining-room	5 lamps.
Drawing-room	3 „
	8 lamps.

No. 4 circuit supplies:—

Lobby (upstairs)	1 lamp.
Bath-room	1 „
No. 1 Bed-room	1 „
„ 1 Dressing-room	1 „
„ 2 Bed-room	1 „
„ 3 „	1 „
Boudoir	2 „
	8 lamps.

No. 5 circuit supplies:—

Lobby (upstairs)	1 lamp.
Boudoir	2 „
No. 1 Bed-room	1 „
„ 2 „	1 „
„ 2 Dressing-room	1 „
„ 3 Bed-room	1 „
„ 4 „	1 „
	8 lamps.

The three circuits downstairs each carry eight lamps, and the two circuits upstairs each carry the same number of lamps, and in this way the amount of current carried will not exceed 5 amperes (see p. 162).

In the dining-room put a five-light pendant in the centre over the dining-table, with two single-light wall brackets and a reading-lamp with a wall plug.

In the drawing-room put a three or a four-light electrolier and brackets on the walls for a more general light. A piano lamp can be supplied by a wall plug.

In the smoke-room put a two-light electrolier with two wall brackets.

In both the dining and drawing-rooms there are two circuits, one feeding the central lights, and the other the brackets and wall plug. If in one circuit a fuse should blow, the room will not be left in total darkness.

In the boudoir a two-light pendant can be placed in the middle of the room and two wall brackets in addition. In bed-rooms a two-light rise and fall pendant fitting can be placed over the dressing-table.

The service mains enter the house and pass through a double-pole main cut-out, then through the double-pole main switch, one conductor passes to the distributing-board, the other passes through the meter on its way to the distributing-board.

Switching Arrangements.—Switches are mostly placed inside the doorway of the room, and all are placed on the one pole of the circuit they control. The actual arrangement of the circuits would be determined from a plan of the house, and the further any room is situated from the distributing-board the greater will be the length of conductors required.

CHAPTER XVI.

THE GENERATION AND TRANSMISSION OF ELECTRICAL ENERGY.

THE **Generation, Transmission,** and **Distribution** of electric current.—Current is *generated* in the power house by alternators or dynamos driven by steam engines or water turbines, &c. The electrical energy is then conveyed by conductors to where it is to be used, or, if this is far away, step-up transformers are used to transform the energy into a small current at high pressure for transmission purposes, and at the receiving end of the line step-down transformers transform it into a large current at a low pressure for lighting and power purposes.

This was very well shown by an electrical firm at the Glasgow Exhibition in 1901, where we saw the working model. Continuous current at 500 volts' pressure from the mains in the Exhibition grounds drove a 30-H.P. motor, which was direct coupled to a 20-kw. alternator, 50 cycles, generating alternating current at 300 volts. The current was then led to a step-up transformer, which raised the voltage from 300 volts to 10,000 volts; next it passed through a step-down transformer (see p. 101), and was reduced in pressure from 10,000 volts to 110 volts. This current drove a single-phase alternating-current motor of 17 H.P. at 110 volts. This last was coupled to a continuous-current generator of 17 kw. capacity, giving continuous current at 100 volts, which was led to the bus-bars on the switch-board, and from thence it was used for lighting purposes and to run small motors. We began with continuous current and ended with it, the intermediate steps being the conversion of it into alternating high-pressure current, and the reconversion into continuous current.

At Telluride, Colorado, current is transmitted along conductors at 40,000 volts' pressure. This is the virtual value of the pressure; to find out the maximum value the student should consult p. 70. From St Maurice to Lausanne current is transmitted at 22,000 volts. It is proposed to transmit current from the Falls of Plombieres, near Mentone, to Lyons (a distance of 111·84 miles) at 56,900 volts, which will be the highest electrical pressure used in Europe.

At the St Louis Exhibition (1904) the conductors, which carried current at 100,000 volts' pressure, showed a remarkable luminous appearance surrounding them. This has been noted in cases of conductors subjected to great electrical stress; it seems as if the air surrounding the conductors becomes luminous. The pressure required to economically transmit current for long distances is found as follows:—

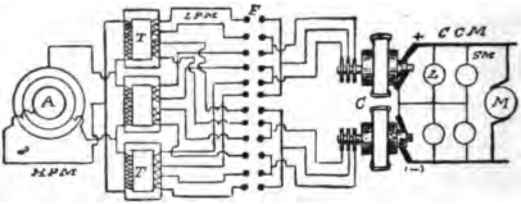

Fig. 168.

The pressure in thousands of volts $= \frac{1}{3}$ of the number of miles required to transmit.

For a 200 mile transmission we would require something under 70,000 volts, for $\frac{200}{3} = 66$.

$\therefore$ 66,000 volts would be required.

Electrical distribution is effected by (*a*) *high-pressure alternating current*; and (*b*) *high-pressure continuous current.* (*a*) It is called *high-pressure alternating current* if it exceeds 250 volts' pressure, but cannot exceed 3,000 volts; extra high pressure when it exceeds 3,000 volts. Current is generated as three-phase alternating (Fig. 168) by one alternator A or more running in parallel at from 2,000 to 6,000 volts, high-pressure mains HPM run from the bus-bars to transformers T placed in substations, and from these the secondary or low-tension cables LPM pass through fuses F to converters C, which give out continuous current to the outers of the three-wire system at 400 to 500 volts. Consumers are joined up either on the + or (–) side of the system and get current at 200 or 250 volts on their lamps, while motors M can be joined between the outers, and get the full voltage across their terminals.

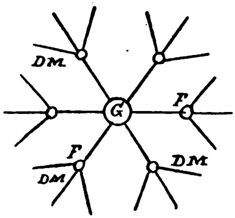

Fig. 169.

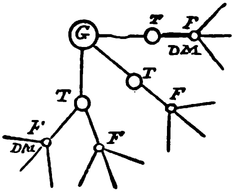

Fig. 170.

Alternating current is always used in long-distance transmission for power and lighting purposes.

(*b*) *It is called high-pressure continuous current* where the pressure at any time exceeds 500 volts. The current is generated by multipolar dynamos at 500 or 2,000 volts' pressure, and is led to substations, where it is reduced in pressure by motor generators or two separate machines coupled together and wound for 1,000 to 2,000 volts on the primary side, and 400 to 100 volts on the secondary; from them current passes by distributing mains to consumers' houses for lighting purposes, running motors, charging storage batteries, or electrolytic processes. *Low-pressure continuous current*, when it cannot exceed 500 volts, is generated by small dynamos of, say, from 100 to 50 volts for lighting shops, houses, &c., and for charging storage cells with two-wire distribution. From the generating station G (Fig. 169) feeders run to feeding points F in the area of supply, and from these the distributing mains DM pass, which carry the current through the service mains to the consumers' lamps. Sometimes high-pressure current is sent from the generating station G to transformers T in the area of supply, and from these low-tension feeders supply the feeding points F (Fig. 170).

The three-wire system (Fig. 171) of distribution, associated with the names of Edison and Hopkinson, is used for installations in central station supply systems. It consists of two or more shunt or compound-wound dynamos, D_1, D_2, which feed a system of lamps. A saving in copper in the return wires is got by using three wires instead of four, *i.e.*, two from each dynamo. The dynamos are joined in series between the mains A, B, and suppose each machine gives off 100 volts, then they keep the mains A, B at a potential of 200 volts (for $100+100=200$). The mains are of a size to carry the current required by half the number of lamps only. The lamps are joined two in series across A, B. The neutral or middle wire C, being much smaller than the outers, connects the junctions of the pairs of lamps and that of the dynamos. When the number of lamps lit between AC is the same as those between BC, the potential is the same along all parts of C, and no current flows along it, and it may be removed without affecting the working. Should a lamp between AC be switched out, then the resistance between AC increases, and therefore the fall of potential becomes greater than between BC. But A, B are kept at the same P.D., and if the difference between AC is increased, it is only by the lowering of the potential of C near the point where the lamp is switched out. But the voltage at D remains the same, so this D.P. causes a current to flow along C to the lamp in strength equal to what flows through a single lamp. If a lamp between BC is switched out, balance is again restored, and no current passes along C.

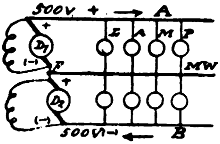

Fig. 171.

If all the lamps on one side were cut out, then C must carry all the current to the lamps on the opposite side, and would require to be as large as A, B. In Glasgow the pressure on the outers is 500 volts, and consumers are joined up between the outers and the middle wire, and are supplied with 250-volt lamps. In order to keep a balance, consumers are joined up alternately on each side of the middle wire, MW or C.

Exercise.—In a three-wire installation, with 200 volts between the outers, there are 12 16-c.p. lamps, taking each 0·4 ampere, lighted on one side, and 17 on the other side. The connection to the middle wire in the street is broken; find the pressure existing on each group of lamps. Normal lamp pressure at terminals $\frac{200}{2} = 100$ volts. Current per lamp $= 0{\cdot}4$. Hot resistance per lamp $\frac{100}{0{\cdot}4} = 250$ ohms. Hot resistance of 12 lamps in parallel $\frac{250}{12} = 20{\cdot}8\omega$. Hot resistance of 17 in parallel $\frac{250}{17} = 14{\cdot}7\omega$. Total resistance of the two groups in series between outers

$$= 20{\cdot}8 + 14{\cdot}7 = 35{\cdot}5\omega.$$

Current in outer and inner—

$$\frac{\text{E}}{\text{R}} = \frac{200}{35{\cdot}5} = 5{\cdot}6 \text{ amperes.}$$

P.D. between lamp terminals of group of

$$12 = 20{\cdot}8 \times 5{\cdot}6 = 116{\cdot}4 \text{ volts.}$$

P.D. between lamp terminals of group of

$$17 \text{ E} = \text{C} \times \text{R} = 5{\cdot}6 \times 14{\cdot}7 = 82{\cdot}3.$$

When the three-wire system was first invented, double dynamos (Fig. 171) were used to run it. Then came a change, where a number of dynamos were used, and these, by means of plugs, could be shifted from one side of the middle wire, MW, on to the bus-bars, BB, of the other side, as the load varied on either side.

Next balancing dynamos, quite distinct from the main dynamos, were used, at first without, and then with, the battery regulating system, and now in all direct-current systems up to date we have not only balancers and batteries, but also boosters (Fig. 172). The balancer booster consists of four dynamos, with their armatures all mounted on the one shaft. The two inner ones, BD_1, BD_2, are the balancers, and have the middle wire, MR, attached to their junctions. Their field coils are excited from opposite sides of the system. The two outer machines, B_1, B_2, are the boosters, the field coils BF + and BF (–) of each join with the middle wire by one end, and by the other with a reversing switch RS*w* (the connections are not shown), so that either can be joined to the + or (–) bus-bar, BB, as required. One end of each booster armature is joined to its bus-bar, and the other to a two-way switch, so that the booster can be inserted between the ends of the battery or cut-out. There is also a cell-regulating switch on either side, BRS*w*. When the load is equal on the two sides of the system (the same number of lamps burning), BD_1, BD_2 run as motors, and drive B_1, B_2. In charging the battery the e.m.f. of the boosters increases the P.D. across the cells due to the generators D_1, D_2, D_3. When the battery is discharging, the e.m.f. of B_1, B_2 is reversed by the switch RS*w* (or automatically in a reversible booster), and so they assist the battery e.m.f. to maintain the proper voltage in the circuit. In short, the boosters boost up the bus-bar pres-

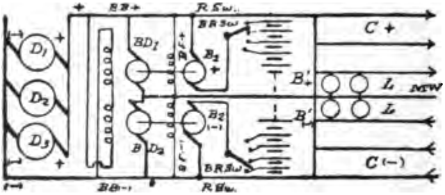

Fig. 172.

sure, and allow the battery to be charged, and they boost or assist the battery pressure when discharging! B_1, B_2 are assisted by means of the battery $B' +$ and B' ($-$) to maintain balance in the system; $C + c$ ($-$) are the circuits, and L are the lamps.

The term **rectified current** means an alternating current which has been converted into a unidirectional intermittent direct or rectified constant current, at varying voltage. It consists of a series of currents flowing in one direction, and at the same time rising and falling like alternating current—40 to 100 times per second. Its use is that, when alternating-current arc-lamps are run by it, their efficiency as regards illumination is greatly increased.

Fig. 173 shows the commutator on a Ganz rectifier (for high-tension current) laid out flat, and also its action. On the high-tension system the arc lights L are run in series on a circuit, the voltage of which is varied to suit the number of lamps in circuit. This high-tension current is rectified as follows:—It is led from the alternator to a transformer T, the primary coils of which are movable, so that it is possible to vary the induction through the secondary coils. From this the current is led to a commutator, C, which is driven by an alternating-current motor running in synchronism with the alternator, so that as each reversal of current on the brushes occurs, the commutator moves round one segment and reverses the direction of the current. When a reversal occurs, the current's direction will reverse; but now the commutator has moved forward one segment, and the current always passes through the lamp circuit in the same direction.

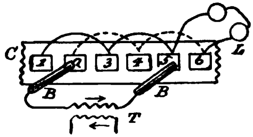

Fig. 173.

Lightning arrestors are mounted on non-combustible bases. One is required for each side of every circuit connected with the generating station, and also for the outside lines, to prevent a lightning discharge getting to the station, burning out the armatures and wrecking the generators, &c. Each should be joined up to two earths, so as to give the flash the shortest road to earth, and at the same time stop the arc which follows the flash.

The Wurtz Arrestor (Fig. 174) is composed of a lot of serrated metallic cylinders, SM, insulated from each other and all placed parallel in a row, seven in number, with the central one earthed, E. The two outer cylinders join the line wires, LW. An apparatus like this does for alternating currents up to 1,000 volts; for higher pressures more groups are put in series. The power-current has not sufficient pressure behind it to make it jump across from one cylinder to another, but a lightning flash jumps across easily. The cylinders are composed of an alloy of zinc and copper, which cannot sustain an arc; each is 1 inch by 3 inches, separated by $\frac{1}{32}$ inch air-gap. It is held that, after a flash has passed to earth, the power-current follows, zinc is burned, and the oxide volatilised, thus forming an insulating atmosphere which prevents the further flow of current, and the arc burns out. There are other forms of lightning arrestors; for instance, *Elihu Thomson's*, *The Westinghouse Co.*; *Garton's*, *Daniell's*, *&c.*

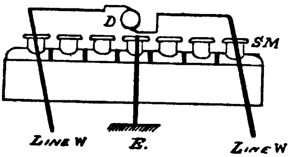

Fig. 174.

CHAPTER XVII.

THE GENERATING STATION.

The Electric Generating Station.—When a town is to be lit up by electricity the Local Authority, composed of the Municipal Corporation, or it may be an Electrical Supply Co., apply to Parliament for a Provisional Order. This Order allows them to supply current for lighting or power purposes, to acquire land, to break up the roadways in the streets, to construct a power station, lay down cables, transformers, junction-boxes, &c., and do everything necessary for supplying electrical energy throughout the town or district. A consulting engineer and architect are engaged, who advise about the system to be adopted—whether high or low-pressure current; the motive power to be used, whether engines or turbines; the area of supply, and site of the generating stations, &c. Then specifications, with plans, are prepared, and copies sent out to electrical and mechanical engineering firms, and they send in estimates for the work, and the offer is accepted which the consulting engineer thinks the best, or the cheapest, as the case may be.

An electrical engineer is appointed to superintend the erecting of the generating station, engines, dynamos, &c., and he is generally appointed to have full charge of the station when in working order.

The site of the power house is generally placed as near the centre of the district to be supplied as possible, as then shorter mains are required, and this reduces loss. (For loss in mains, see p. 154.) It is best if the site can be fixed upon near to a river and a railway at the same time, as condensing engines reduce the coal bill, and the charge for cartage of coal is saved if a branch railway line runs into the works.

The buildings consist of a boiler house, coal store, chimney stack, engine and dynamo house, switch-board room, offices, stores, workshop, and testing room.

Storage cells are always fixed up in a separate room. Brickwork or stone, laid in cement and concrete, are used for the foundations for the machinery. The coal bunkers should allow of a store of coal supply for three or four weeks.

A travelling crane runs along the whole length of the buildings, above the machinery, which is capable of raising the heaviest weight likely to be moved.

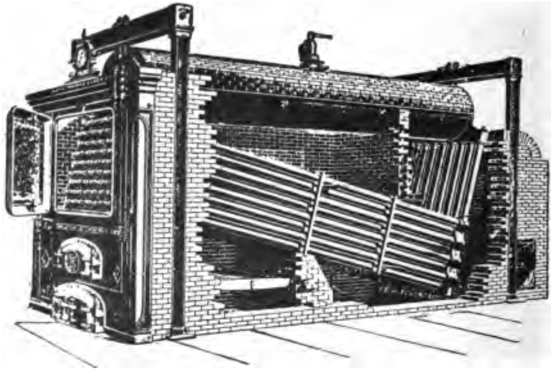

Fig. 175.

The Boilers.—The *Lancashire* type of *boiler* is much used. It is a large cylindrical boiler, having two furnace flues, and set in bricks. The furnaces are generally fired alternately. There may be two boilers, placed side by side, or a battery of them. This boiler steams well, is very trustworthy, and with moderate repairs may be quite serviceable at the end of ten years. It is said to be less costly than many other types.

The Water-tube boiler has the furnace flame and hot gas outside of, and these act upon, parallel rows of tubes, say from 4 inches to 6 inches diameter, which contain water and steam. These wrought-iron and lap-welded tubes connect with a receiver or steel drum; they are placed in an inclined position. The upright connecting tubes, or headers, are of wrought steel (see Fig. 175, which shows a Babcock and Wilcox water-tube boiler with part of the brick wall removed to show the tubes). The heating surface is very great and effective, and the heat acts upon such small quantities of water, contained in the tubes, at any one place that steam rises very rapidly, and if a sudden demand for steam arises, as in winter owing to fogs, this is easily met owing to the rapid steaming power of this boiler.

One of these boilers may last, perhaps, half a century, for it has new tubes inserted as required every year of its life, so it is easily repaired, but costly in upkeep.

These boilers are said to be very safe, as there is little liability to serious explosions. They withstand all ordinary working pressures: one at the Baltimore Loco Works, Philadelphia, ran at 235 lbs. pressure per square inch. We have heard of 310 lbs. pressure per square inch on one of these boilers.

The Stirling boiler consists of three steam and water drums, and one mud drum, connected together by three main banks of tubes, with short circulating tubes between the steam and water drums. The drums are from 36 inches to 42 inches outside diameter. There are also five-drum Stirling boilers made; one of these boilers will evaporate 25,000 lbs. of water per hour at the rate of 4 lbs. of water per square foot of heating surface.

Mechanical stokers are often used for stoking purposes, and are attached to the boilers. The feed-water is got from a storage tank to which a supply of water is taken from the street mains.

The *feed-pumps* are always in duplicate. Generally they are of the direct acting type, and by working slowly at 25 strokes per minute, the water level in the boiler is kept constant, with a full supply of steam.

Sometimes the steam from the boiler is led through a *superheater*, which consists of a series of pipes which are exposed to the waste gases from the boiler to heat the steam (the Smi-Schmidt superheater is separately fired from the boiler). Economy is obtained by superheating the steam. It has been proved that the compound type of engine working with superheat has proved more economical than the triple-expansion engine without superheat. Tests have also shown that engines on an average use from 30 per cent. to 40 per cent. less steam with superheat than with saturated steam. Condensing engines help greatly to reduce the coal bill, if water can be had cheaply and there is a good supply of it, hence condensers are used, if possible.

The four principal types of steam engines used for electric lighting and power purposes are:—

The Slow-speed Horizontal Compound, or triple-expansion engine. The speed varies from 60 to 130 revolutions per minute. Flywheels are large, and Corliss valve-gear is used. There may be two cylinders placed tandem, or four cylinders, each pair being in tandem. Cranks are overhung, with only two main bearings. An engine of this kind is suitable for very large powers such as 4,000 H.P., and may consume 30 lbs. of steam per I.H.P. per hour when driving a 700-kw. generator. The compound engine working with superheated steam is said to be more economical than the triple-expansion type without superheat.

The Vertical Cross-compound engines of moderate speed, with overhung cranks, and only two shaft bearings. The cylinders are mounted on hollow cast-iron columns which form the crosshead guides, and enclose the cranks and connecting rods. A heavy flywheel is keyed on the shaft, between the cylinders, and on this the moving parts of the generator are built, forming a flywheel alternator. In the case of a continuous-current plant, the armature either forms the flywheel or it is mounted on the shaft close to the flywheel. Speed varies from 80 to 150 revolutions per minute, and the engines may indicate up to 3,000 I.H.P. They take up only a small amount of floor space by what horizontal engines do, and the wear of both cylinders is less; but they require massive foundations to prevent vibration. The valve-gear is of the Corliss type. This form of engine is now, to a great extent, displacing the horizontal type.

The High-speed Vertical enclosed engines, such as the Willans (single-acting), the Belliss, Sentinel, Peache, Alley & M'Lellan, Westinghouse high-speed engines, &c., are much used up to 250 kw., coupled direct to the generators. Speed varies from 200 revolutions to 500 revolutions per minute, according to size.

The Belliss is a double-acting engine (Fig. 176), the high, HP, and low-pressure cylinders, LP, are arranged side by side, a piston-valve, PV, driven by a single eccentric, distributes the steam to the cylinders. At the lower part of the eccentric is an oil-pump, OP, which forces oil along the oil tubes OT to the hollow crankshaft CS and the cranks. The governor G is fixed at the opposite end of the shaft to the flywheel FW, and controls the cut-off by varying the position of the eccentric. When running, steam is admitted simultaneously to the top of one cylinder and the bottom of the other one, and being double-acting the engine runs quietly without knocking and very steadily. It is much used where there is a suddenly varying load, as, for instance, in running tramcars. The engine is entirely enclosed. The double-acting engine is now displacing the single-acting engine, as, owing to the forcing of oil through the bearings, this permits of high speeds with closely-fitting brasses, and gives more power for weight and space occupied; also the air-buffer in the single-acting engine is responsible for much friction, leakage, and heat radiation.

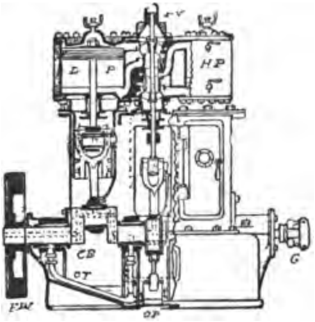

Fig. 176.

Turbines or Rotatory Engines.—In these the circular motion is produced directly by the steam, and there are no reciprocating parts, such as piston-rods, connecting-rods, or eccentric-rods, &c. There are different types. The *De Laval turbine* (Fig. 177) is a single-expansion impulse turbine. High-pressure steam passes through one or more nozzles N, placed diagonally to the vanes, V, of the turbine wheel inside the case. These nozzles are so constructed that they expand the steam and increase its velocity. The speed of these turbines is enormous: a 5-H.P., with a 4-inch diameter wheel, runs at 30,000 revolutions per minute, and a 300-H.P., with a 30-inch wheel, runs at 10,600 revolutions per minute. This is too high for practical purposes, and a gear is arranged for a reduction of speed of 12 to 1, and 10 to 1. This turbine is said to be good for driving dynamos for all powers up to 200 H.P. or 300 H.P. It requires scarcely any foundations and little attention.

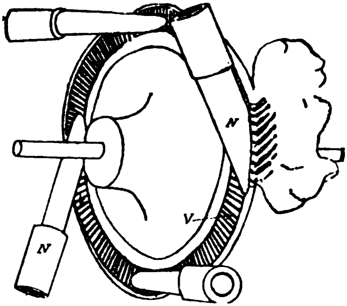

Fig. 177.

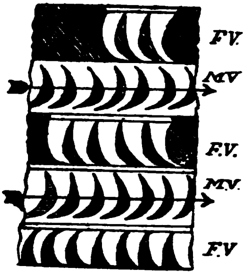

Fig. 178.

The turbine shown diagrammatically in Fig. 178 is what is known as the multiple expansion reaction type, and was invented by the Hon. C. A. Parsons. The steam acts on a large number of sets of vanes in succession, these being so arranged that the steam gives up a portion of its energy to each. After entering the case the steam is directed by the fixed vanes FV so that it flows on to the moving vanes MV at the proper angle; after passing through the ring of moving vanes MV it again passes through a ring of fixed vanes FV, and so on through whatever number of rings is necessary. The first turbo-dynamo was constructed by him in 1884, of 10 H.P., running at 18,000 revolutions per minute. The armature was 3 inches in diameter.

A large modern turbine may have as many as 30,000 vanes.

Parsons' turbines run at 3,000 revolutions per minute for the large, and 10,000 revolutions for small machines per minute, according to voltage and frequency. Compare the speed of a 100-B.H.P. De Laval turbine at 13,000 revolutions per minute, and a 100-I.H.P. Willans' engine at 460 revolutions per minute.

The efficiency of the turbine greatly depends on the degree of vacuum maintained in the condenser.

They are now being built from 4,000 to 6,000 kw. capacity. Among the advantages claimed are the following:—Greater power from a given size — thus, a turbine corresponding to a 6,500-H.P. reciprocating engine will give out 10,000 H.P. They take up less space than reciprocating engines of the same output. Vibration is reduced to a minimum. No oil is required inside the wheel casing, so the exhaust steam can all be condensed and used to feed the boilers. Few repairs are required;* a 600-H.P. turbine ran under load for 7,000 hours (two years of ten hours' work per day), and then only required the reseating of a double-beat valve. Speed rises rapidly after starting. They stand a high superheat of steam, and this, combined with a good vacuum, gives great economy in steam consumption. A 500-kw. turbine took about 20 lbs. per kilowatt hour at full speed, with 140 lbs. pressure, 100° Fahr. superheat, and a vacuum of 27 inches.

Turbines are being much used for running generators, especially where condensing water can be had cheaply.

At these high speeds, with a continuous-current dynamo, carbon brush blocks vibrate greatly, set up heating and undue wear. Brushes of flexible wire gauze, preferably of brass, maintain good contact. Where carbon blocks are used the brushes must be automatically shifted according to the change of load, or else the machine must be provided with commutating poles or compensating winding. By these last means sparkless commutation is secured with fixed brushes up to 100 per cent. overload in plants for traction purposes.

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* See p. 877, *Journal of I.E.E.*, vol. xxxiii., July 1904.

Turbo-generators are now being used in generating stations with good results, especially where condensing water can be had. Fig. 179 shows one in Manchester.

A 3,000-kw. turbo-alternator is running at Frankfort-on-Main.

A 1,500-kw. turbo-alternator is running at Newcastle-on-Tyne.

A 1,500-kw. turbo-alternator is running at Sheffield.

An 1,800-kw. continuous-current turbo-generator is running at Manchester, peripheral speed of commutator is 6,000 feet per minute.

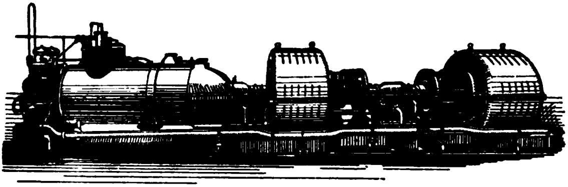

Fig. 179.

A 500-kw. Curtis continuous-current turbo-generator is running at Cork.

To run the Metropolitan District Railway in London three turbo-generators are installed, each of 5,000 H.P., and generating current at 11,000 volts. The Clyde Valley Electrical Power Company, at Yoker, have two Westinghouse-Parsons turbo-generators, of the double flow pattern (steam entering at the centre and exhausting at both ends), each of 3,000 H.P., at 1,500 R.P.M.

Gas engines are made not only to run private installations, but of late years they have been put into corporation electricity works, owing to their large sizes, and are competing successfully with steam engines. The smaller sizes of engines are driven by town gas, and any engine is said to give 1 B.H.P. per $1\frac{1}{2}$ lb. to $1\frac{3}{4}$ lb. of coal consumed. The larger sizes, for generating public supply purposes, are more cheaply run by means of producer-gas plant. The three principal systems in use are:—(1) The *Mond system:* bituminous coal slack is used in the gas-producers, and one ton will yield 140,000 to 160,000 cubic feet of gas, and at the same time gives off a by-product, sulphate of ammonia. One ton coal yields 90 lbs. of this chemical. This is confined to installations in which large powers are required, such as 500 to 1,000 H.P. units, and these would supply current at half to two-thirds the price of a similar steam-driven station. (2) The *Dowson system*, which consists in passing a mixture of air and steam through anthracite peas or coke; a gas is given off which is suitable for gas engines. It is said to cost 2d. to 4d. per cubic foot to manufacture, and gives off 150 B.T.U.'s per cubic foot; 1 lb. or 1½ lb. of coke per I.H.P. of engine is required per hour. This system is cheaper than compressed air, water, or steam power. (3) The *Suction system.* In this a good quality of anthracite peas is used, and use is made of the excess heat to produce steam, which is drawn through the producer furnace combined with air by the suction-stroke of the engine. The steam enriches the gas and cools the firebars. No gasholder is required, and the producer can be fixed up close to the engine. This system is used a good deal for small powers; but large installations of, say, 500 H.P., are run by it also.

Blast-furnace gas has been proposed to be used for running large generating stations. The Cockerill Co., of Seraing, Belgium, exhibited at Paris in 1900 a 600-H.P. blowing engine: the gas was generated from five blast-furnaces, and on trial 900 I.H.P. were got, 725 B.H.P. when 100·8 cubic feet of gas per hour were consumed $\frac{\text{B.H.P.}}{\text{I.H.P.}} = \frac{725}{900} = 80$ per cent. efficiency. This same firm showed at the St Louis Exhibition in America (1904) a 3,000-H.P. gas engine with two cylinders, each 51 inches diameter; engine ran at 85 revolutions per minute.

An 800-kw. three-phase generator is running at the Phœnix Steel Works, Laar, near Ruhrort, Germany, and is driven by a single-crank blast-furnace gas engine.

The efficiency of a gas engine is greater than a steam engine, and it has been shown by tests that, instead of utilising 12 per cent. of the total energy of the coal in useful work, as in the steam engine, we are able, in the gas engine, to use at least 27 per cent. of the gas or gaseous fuel; but, owing to the mechanical efficiency, we only obtain 20 per cent. of the total energy of the gas in useful work in small sizes of engines.

The Oil engine (Fig. 180) is useful for private installations in localities where gas cannot be got, and a supply of petroleum oil can be had almost anywhere, and is very cheap. An attendant is only required at starting and stopping, with occasionally oiling the bearings. A gas engine gets gas direct to the cylinder; but, in this engine, the oil is supplied, not as a gas, but as a liquid, to the cylinder; it passes, drop by drop, into a separate appendage on the cylinder called the "vaporiser," where it is converted by the heat into gas and passes to the cylinder and mixes with air to form an explosive mixture. The cycle is the same as a gas engine, viz., a four-stroke cycle consisting of admission, compression, explosion, and exhaust. Hornsby, of Grantham, tested a 125-B.H.P. oil engine they had made. In ordinary working the oil fuel averaged about 2s. per 100 H.P., as compared with 3s. for steam and 2s. 5d. for the most economical power gas engine, so the oil engine is by far the cheapest motive power of the three.

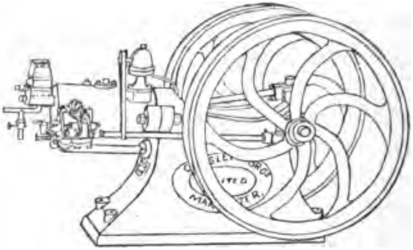

Fig. 180.

The *Diesel oil engine* is said to be a great improvement on the existing type, and very economical. One was shown at Glasgow Exhibition in 1901. Instead of the engine drawing in a mixture of air and oil vapour and then compressing it, it compresses the air by itself to over 500 lbs. pressure per square inch, thus raising its temperature to about 1,000° C., and then into this compressed air is sprayed oil, when combustion occurs and drives the engine. The engine is very steady and reliable. No external flame, hot tube, or electric spark is used to fire the charges, only the compression in the cylinder. The makers claim that the engine runs on $\frac{1}{10}$th of a penny per B.H.P. hour. This means, they say, that an installation of 250 B.H.P. costs £265 per annum for fuel, running 54 hours per week, whereas the cost of running an ordinary steam installation would cost six times as much. These engines are running power stations in some parts of England.

The Hydraulic Turbine

was introduced in France by Fourneyron in 1827, and by Fairbairn in England, and Boyden in America.

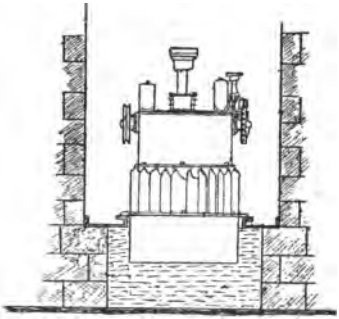

Fig. 181.

The "*Hercules*" turbine (Fig. 181) is made with a horizontal or a vertical shaft, and is fitted inside a steel casing, or put in a brick or stone flume, if not in an old wheel-house. It consists of a water wheel, through which the water impelled by the "head" passes, and is guided by channels in the wheel itself, and usually by other passages exterior to itself in what are called the "gate" or guide curves, and these cause the water to impinge on the wheel buckets or blades at the proper angle to make it revolve with the highest efficiency. Turbines are called "outward flow," "inward flow," and "parallel flow" according to the direction of the water passing through them, and their efficiency is about 75 per cent. to 80 per cent.

They are useful for driving dynamos where a good head of water can be depended on. They are much used in Switzerland, and in America; for instance, at the Niagara Falls power station there are a number, some of them driving 5,000-H.P., and others 10,000-H.P. generators.

Recently the largest generator in the world has been erected at the Niagara Falls, of 12,000 E.H.P., and is driven by a turbine.

In our own Highlands at Fortwilliam there are two 60-H.P. vortex turbines, and one of 40 H.P., running the electric plant for producing calcium carbide, aluminium, &c.

Lord Kelvin has frequently urged "that the development of electricity from waterfalls running to waste in our Highland glens would be the means, in a short time, of bringing a large measure of industrial activity to the people of the Highlands and Islands of Scotland."

INDEX.

◆

SYMBOLIC LETTERS.

B = flux density or induction.
B.H.P. = Brake horse-power.
B.O.T. = Board of Trade unit.
B.T.U. = British thermal unit.
C.G.S. = Centimetre-gram.-second.
C.P. = Candle-power.
D.B. = Double break.
D.P. = Difference of potential.
D.P. = Double pole.
E. = Earth.
E.H.P. = Electrical horse-power.
E.M.F. = Electro-motive force or voltage.
H = Magnetising force.
H = Horizontal component of earth's magnetic force.
H.P. = Horse-power.
I = Intensity of magnetisation.
J = Joule's equivalent.
K = Capacity.
L = Inductance.
M = Magnetic moment.
mm. = Millimetre.
m.f.d. = Microfarad.
M.M.F. = Magneto-motive force.
P.D. = Potential difference.
P.W. = Watts.
Q = Coulomb.
R = Reluctivity.
S.B. = Single break.
S.P. = Single pole.

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